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LET THERE BE BREAD

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BY

ROBERT BRITTAIN

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Wonders are many on earth, and the greatest of these
Is man, who rides the ocean and takes his way
Through the deeps, through wind-swept valleys of perilous seas
That surge and sway.

He is master of ageless Earth, to his own will bending
The immortal mother of gods by the sweat of his brow,
As year succeeds to year, with toil unending
Of mule and plough.

* * *

The use of language, the wind-swift motion of brain
He learnt; found out the laws of living together
In cities, building him shelter against the rain
And wintry weather.

There is nothing beyond his power. His subtlety
Meeteth all chance, all danger conquereth.
For every ill he hath found its remedy,
Save only death.

—from the ANTIGONE of Sophocles,
as translated by E. F. Watling

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FOREWORD

AT THE END of the eighteenth century many liberal-minded people in England hoped that the American Revolution, followed by one in France, marked the beginning of a new age of democracy when governments elected by the people would put an end to poverty with its intolerable evils of hunger and preventable disease. The Rev. Mr. Thomas Robert Malthus thought that such hopes were ill-founded. He wrote his famous essay on population in which he argued that hunger could never be abolished because population increased faster than food production unless the growth of population could be limited by birth control.

Fifty years later in the "hungry forties" of the nineteenth century it looked as if Malthus had been right. The population of Europe had increased from about 180 to 260 million and there was an increase in North America of nearly 20 million, almost entirely emigrants from Europe and their descendants. The increase in food supply had not kept up with the increase in population. Especially in the rapidly growing industrial towns of England, bread was so scarce and expensive that children six years old had to work in cotton mills to help earn food for their families. Hunger produced social unrest and threats of revolution. The prediction of Malthus had so far been justified, and most people resigned themselves to the view that hunger was inevitable for a large proportion of the world's population. After Darwin and the theory of the survival of the fittest, this was regarded by some as a wise dispensation of Providence. Hunger provided for the elimination of the unfit, the unfit being those who failed in the competition for success in making money.

In the next fifty years, however, although the population of Europe increased by another 150 million, the supply of bread increased even faster. The increased supply came partly from increased crop yield through the development of agriculture, and partly from the import of wheat from the seemingly inexhaustible virgin lands of North America. Bread was now so plentiful and so cheap that in England and other western European countries actual hunger almost completely disappeared, and Malthus and his theory of population were forgotten.

Another jump of fifty years brings us to the present time, when the food position of the world is not unlike what it was in Europe in the revolutionary "hungry forties" of the nineteenth century. Since 1900 the population of the world has increased by about 50 per cent, from 1,608 million to nearly 2,400 million. If it continues to increase at the same rate, it will reach 4,000 million during the lifetime of our children.

There is another factor, unknown to Malthus, which adds to the gravity of the problem. Since the "dust-bowl" scare in the United States in 1934, much more attention has been paid to soil erosion. Large areas in the world which were once fertile have become barren, and in most areas the loss of fertile land is continuing.

This rising tide of population and the falling reservoir of food resources constitute, apart from the immediate issues of peace or war with which it is not unconnected, the greatest issue facing mankind today. Although food production has increased in some countries, notably in North America, it has decreased in others, and the food supply of the world per head of population is less today than it was before the last war. Social unrest and revolution in Asia, and the spread of communism with its promise of an economy of plenty for the masses, are largely the results of hunger.

Many now believe that Malthus was right, and that the only solution of the problem of the pressure of population on land is birth control. But there are religious objections to the teaching and practice of birth control, and in the nations where population is increasing fastest the masses are illiterate and difficult to reach with education on this subject. It may be true that the only long-term answer to the problem will prove to be birth control. It usually begins to be practised only when the standard of living and education rises.

This has already happened in western Europe, where the increase of population has slowed down since 1900 and is now believed to be on the decline. But it will be a long time before the two-thirds of the world's population at present suffering from hunger and malnutrition reach the standard of living and education of the nations where the growth of population is being arrested. We must look forward to our children's inhabiting a world with a population double what it was before the last war. Can the earth support 4,000 million people? This brilliantly written book will convince the unbiased reader that, with modern science, it can be done.

Unfortunately, most of the industrial products needed to increase production quickly enough to allay social unrest and revolution in the near future are in North America and Europe. If hunger is to be abolished, there must be international collaboration in a world food plan which will link up the undeveloped resources of the hungry nations with the industrial capacity of the well-fed nations.

Such a plan was submitted in 1946 to the governments of all the countries in the world by the Director General of the United Nations Food and Agricultural Organization. A policy on similar lines has been advocated by others, notably by Stringfellow Barr in his recent publication *Let's Join the Human Race*. Governments might well consider whether a world food pact in which all nations were asked to join, whatever their political ideology, might not be a more effective means of bringing about peace than military pacts. Peace and plenty go together. There will be no peace in the world as long as half of its people suffer from hunger and poverty, knowing that food in abundance is entirely possible. This book gives the most complete account I have seen of what can be done with modern science to create a world of plenty.

John Boyd Orr

Newton of Stracathro
Brechin, Angus

INTRODUCTION

I. THE GREAT INVASION

When you arose from your bed this morning, there were some eighteen thousand more people in the world than were alive when you went to sleep. By bedtime tonight, the numbers of the living will have jumped another thirty-seven thousand. Every year you live, there are on this planet approximately twenty million more human beings than there were the year before.

It is important to realize at the outset that this staggering figure of fifty-five thousand per day is not the birth rate of the human race: it is the *survival rate.* In some countries the actual birth rate is falling; in others it is rising. But in nearly all, people in general are managing to hold on to life a little longer. It is this lengthening life span, coupled with a healthy rate of reproduction, that is responsible for the fact that at every moment the earth is called upon to support a larger number of human beings.

Looked at from certain points of view, this constantly increasing population might seem to be a great blessing. After all, the primary test for the successful adaptation of any species to its environment is its ability to reproduce and maintain itself in larger and larger numbers. The human race has been driving for this goal ever since it first appeared on the planet, and to a nineteenth-century devotee of progress it might appear that we have reached a kind of millennium. The fact that fewer babies are dying in the first months of their lives, and that more adults are living through the full span of their productive years would hardly seem a cause for woe. Every year there are twenty million more companions to share in the collective labour that is our human lot; twenty million more brains to explore the still boundless regions of ignorance by which we are surrounded; twenty million more chances for men to become, in truth, only a little lower than the angels. One might suppose that these oncoming millions ought to be greeted with universal rejoicing.

Instead, the news of their arrival is received in many quarters with consternation. We have no exact statistics on world population, but the most reliable estimates place our present numbers at somewhere between two and a quarter and two and a half thousand million. Experts on population assure us that by the end of the present century the human family will number at least three and a half thousand million, or possibly even four. The reason these predictions are alarming is that they are interpreted to mean that fifty years from now three people are going to have to live in the space now occupied by two, and eat their food and wear their clothes and use their share of the water, the electricity, the oil, the steel, and all the other essentials of modern life. According to this view, if you are at present consuming three meals a day, you are going to have to get along with two, and every other item of consumption is going to be reduced accordingly.

Of course, this fate is not inevitable. But it would certainly seem to be in store for us unless humanity figures out some way to accommodate these extra millions. Unless we devise ways and means of filling these additional stomachs, every single one of us will have to take the consequences. If you think that over, you will see that of all the problems we in this harassed century are called upon to solve, this gigantic invasion of our planet is probably the most insistent. It will not wait fifty years to become acute, nor can we leave it to the next generation to solve. Within a bare seven and a half years a horde of people as large as the entire population of the United States will be added to the millions already clamouring for a share in this world and all its goods. And the stresses and strains are already apparent.

It is not surprising that many people, on becoming aware of the population problem, have thrown up their hands in despair. Experts have calculated that around the end of this century the rising curve will level off, and that for a long time thereafter world population will remain somewhere near three and a half thousand million, before beginning a very gradual decline. But this promised halt in the growth of our species gives little hope to certain observers. The prospect of three and a half thousand million people struggling for a livelihood on this little earth fills them with dismay and terror. They are terrified because they believe that such a struggle can end only in universal misery and the eventual extinction of the race. In their opinion, the planet simply cannot support such masses. As evidence of the limitations we are up against, they point out that half the people now living have never in their lives eaten what we would call a square meal. Hunger is, for millions of people, the primary fact of life. And the misery of their hunger afflicts us all, for it breeds disease and crime and social desperation whose results all men must cope with. When there are not enough of the material necessities to provide a decent living for the present population, how can we hope to feed a larger one?

Behind this unhappy conclusion lie a number of arguments. Basically, they all rest on an assessment of the resources men must use to provide their daily bread, and on certain assumptions that are made about those resources. It is maintained in the first place, that since the land now under cultivation is not producing sufficient nourishment for the present population, it is idle to suppose that it could produce enough for a thousand million more people. In the second place, we are told that there are no new lands that can be opened to cultivation. The human race has spread around the globe, and no potential wheat fields remain to be discovered.

Finally, those who see only increasing misery ahead point to a truly alarming fact. Many of the resources of land, water, minerals, and power, upon which even the lowest standards of living must rest, are declining with alarming speed. The United States are cutting down forests at a rate 50 per cent faster than they are growing. All over the world the rivers run into the sea, taking with them topsoil that can never be replaced. During the short period of the last fifty years human beings have used up a far larger amount of minerals than were consumed during the entire span of time before 1900; and once coal, oil, iron, and the rest are gone, they are gone forever. It is true that despite this enormous consumption "there is no serious and *immediate* over-all and irreplaceable shortage of any essential mineral," on the authority of Dr. Hugh L. Keenleyside, former Deputy Minister of Mines and Resources in Canada and the present director of the United Nations Technical Assistance programme. It is also true that, as Dr. Keenleyside has pointed out, " . . . a great proportion of the minerals used during the last five decades has been criminally wasted in the waging of the most destructive wars in history." But this does not alter the fact that if we go on at such an alarming rate we shall eventually destroy the possibility of civilized life on this planet. The graph of most natural resources is going down, while the demand soars to unprecedented heights. From this fact it is argued that we have not enough to supply our present needs and in the near future we shall have progressively less and less.

It is a very persuasive argument; indeed, hearing it is less like being persuaded than like being hit on the head with a club. If the generality of mankind should accept it, there seems no doubt that the race would be done for. However, it might be well to realize that the problems which have provoked this line of argument are not new in human history. They have arisen repeatedly in the past, they have frequently been serious in the extreme, and they have sometimes persisted for very long periods; but they have always been solved.

From the time of man's first appearance on this planet he has had to contend with food shortages, and at first it took him an incredibly long time to learn how to solve them satisfactorily. If you attempted to recount the entire story of human experience in five hundred pages, and to do it by arbitrarily allotting one page to each thousand years, for some four hundred and ninety pages your book would be concerned with the wanderings of a savage creature, ignorant of tools, unable to farm, trusting to chance for survival in the manifold terrors of the jungle. He was, in the anthropologist's terms, a food gatherer and not a food producer. Over and over again this creature found his accustomed hunting grounds supplying too little food for his growing family. When this happened, he did the only thing he knew: he moved to virgin territory where the prospects looked better. Although migration did not offer a permanent solution to the human food problem, it did enable the race to survive in small nomadic groups as long as there were always new hunting grounds to go to.

Eventually came a series of scientific inventions that radically altered this pattern of shortage and migration. A bone or a stone was sharpened and became a hoe; man began to fashion other simple tools and to scratch in the earth small furrows for planting seeds. Edible plants, once they were cultivated, yielded far more than they were able to in their wild state where most of their energies had to go into the struggle for survival. Similarly, when wild animals were captured and tamed, instead of being shot for food, the herds increased instead of diminishing, and they yielded milk for human consumption as well as meat.

The establishment of the first settled agriculture is an example of what anthropologists call a technological revolution, because it resulted from the use of scientific inventions and it produced a fundamental change in the economy of production and consumption. It was only the first in a long series of similar revolutions which have been recurring with increasing frequency ever since. All of them seem to have produced the same general results, and these results have a bearing on our present dilemma.

In the first place, after every technological revolution in the past the survival rate has risen sharply. Soon the resulting pressure of population has put a heavier drain on the available supplies, and food shortages have appeared. As the results of the Industrial Revolution began to be felt in the island of Britain, for example, the population multiplied *two and a half times* within a fifty-year period, from six and a half million in 1750 to sixteen and a third million in 1801. Furthermore, at each higher stage of technology man has used a larger amount of the resources stored in the planet, not merely because of his greater numbers but because of his new and enlarged requirements. A stone-age society has no need or use for paper or natural gas, and the glory of Solomon did not require uranium for its realization. But as each higher stage succeeded a lower one, increased demands have aggravated existing shortages and created new ones.

But technological revolutions bring their advantages as well as their difficulties. The new techniques have always enabled men to produce a great deal more than they did before. From the fall of Rome to the French Revolution, according to Sir Herbert Broadley, grain yields in Europe increased not at all; they remained at only ten bushels or less per acre. In Pieter Breughel's wonderful painting, "Summer," you can see one of those ten-bushel-per-acre wheat fields as it looked in the sixteenth century. It is an uncommonly fine one; for since the entire painting is a glorification of man's productive labour bringing forth the bountiful richness of nature, Breughel chose the best model he could find and may even have improved on it. Yet if you look closely, you will see the pitiful inadequacy of that wheat: inedible straw standing up shoulder-high, and on the top of each stalk a tiny, nubbly head no bigger than a man's smallest finger.

After the scientific and industrial revolutions of the seventeenth and eighteenth centuries, however, European grain yields suddenly began to increase. By 1850 French farmers were harvesting fourteen bushels per acre, while in Germany the average yield had gone up to sixteen bushels, and in England to twenty. Fifty years later these figures had increased to twenty bushels per acre for France, thirty for Germany, and over thirty for England. Throughout the first half of our present century they have continued to rise.

Another striking result of these economic revolutions is that a new technology always seems to make it possible for human beings to proceed to still further inventions and developments much more rapidly. It took hundreds of thousands of years for man to discover how to make the simple stone tools that changed him from a food-gathering savage to a food-producing barbarian. But within five or six thousand years this neolithic cultivator was making implements of bronze and copper, and thereby increasing his productiveness to the point where farmers could supply enough surplus to support some people who were not farmers, people who could devote their energies to building cities, constructing irrigation canals, devising calendars and religions and codes of law. So great was the impetus given by these developments that in less than two thousand years these city-dwelling, seafaring peoples were working with iron and writing with an alphabet and coining money. Within five or six centuries after these inventions, they were laying the foundations of Graeco-Roman civilization. Today the speed with which new scientific knowledge can be applied to practical problems, and can lead on to the discovery of still newer knowledge and techniques, is one of the most obvious facts of our common civilization.

It is clear that the technological achievements of the last half century have brought us to the threshold of another period of greatly increased productivity. It is also true that the new technology has brought new problems with it. Expanding knowledge and skill, especially in medicine and public health, have given more of us the opportunity to live to manhood and age, and this increasing power of survival is undoubtedly creating a serious population problem. Naturally, also, the maintenance of a higher civilization demands a higher per capita consumption of the world's resources. Nevertheless, it is important to remember that such problems are the normal result of technological development; they have been encountered at every stage of history.

In the past, humanity has met them by opening up new lands to cultivation and by increasing the yields on the land already in use. These methods have worked in earlier periods, and there is every reason to believe they will work again, especially if they are accompanied by widespread use of a third and more modern instrument: conservation in all its many forms.

The human family does actually have, today, the collective knowledge and the necessary material means with which it could produce all the food it needs. Despite the ferocity with which men have laid waste and plundered this long-suffering planet, it could still support 4,000 million inhabitants or more, and support them in decency and comfort. Although we do not hear much about it in these days when hysteria monopolizes the headlines, man's creative genius is in truth more vigorous than his demon of destructiveness. Such statements may sound fantastic to ears accustomed to hearing the other side, but the evidence is overwhelming.

Before we examine some of this evidence, lest we raise our hopes to impossible heights, one factor in the situation must be clearly understood. There is no material excuse for anyone in this world to be hungry now, and there will be no such excuse fifty years from now; but this does not mean that the primary problem of twentieth-century man is going to solve itself automatically. Nature has never been generous, and even the advent of atomic power is not going to make her change her habits. Although the survival of the race is perfectly possible, and survival in conditions such as only a few favoured individuals have at times and in scattered places achieved, it will require

Herculean efforts to bring it about. Many of the choices we shall have to make will be difficult, and some of us may find them highly objectionable. We may, indeed, refuse to make them, preferring to take ourselves into extinction along with the dinosaurs and other species that outgrew their ability to find food. Nevertheless, we are not doomed in advance. In the duel with death, the universal death of our race, we have the choice of weapons. It is the possibility of choice that makes us human.

As the food problem becomes more acute, men are increasingly studying these assets that do unquestionably exist on the credit side of the ledger, and are asking how they can be effectively used. If there is a shortage of cultivated land in the settled areas of the planet, does this mean that we have come to the end of our migrations? Or do there still remain new areas that can be opened up, and what are the chances of making them productive? Must we abandon forever those regions that once overflowed with milk and honey, but now lie barren and desolate? Or can they be revived, and made once more the support of human life? If insects, rats, and fungi are now destroying annually thirty-three million tons of rice and bread grains—enough to feed the entire population of the United States for a full year—do we have to call such appalling losses "inevitable," or can the depredations of these parasites be stopped? Are there any untapped sources of food, and of power that can be used to produce food, which we can now begin to exploit? And those great natural forces we have recently learned how to release—can we use them not to destroy life but to nourish it?

In attempting in the following pages to answer these questions and to make some survey of the instruments for increased production which man now has in his hands, it has been necessary to impose a number of restrictions on the material that can be included. In the first place, man's creative capacity is so enormous, the number of his ideas, his skills, his clever inventions, and workable tools so vast, that in order to give a readable account of it one is obliged to be highly selective. No exhaustive catalogue is here attempted; for almost every example that has been cited, a large number of similar and related items have had to be omitted. What is attempted is a descriptive account of our scientific and technical resources, sufficiently comprehensive to indicate their kind and quality and the potential productiveness their full use would ensure.

It is an account of work already completed and tested. In a few instances the scientific data that are described have not yet been applied on a large scale, and one of course has to do a certain amount of guessing as to the cost and the practicability of applying them. But when work has been thoroughly tested in the laboratory, and the usefulness of some new tool has been established without question, it seems proper that this new instrument should be included in the inventory of our assets. Unproved theories, on the other hand, have been omitted. Occasionally one is mentioned as an interesting speculation and nothing more, but it is not used to support any conclusions.

Furthermore, the survey has been deliberately limited to the production of animal and vegetable materials which are suitable for human consumption. No account has been taken of the food that may be synthesized from inorganic material, although so great an authority as Dr. Karl T. Compton has assured us that synthetics constitute "a food reservoir of incalculable magnitude." But Dr. Compton has suggested that this reservoir will not be drawn upon till the world faces a real inability to produce enough of the more conventional foods, and we are not faced with this problem at present.

What we must face are problems of bringing more acres under cultivation, of increasing the yield on the acres we are already using, and of conserving the supplies we have. At the present time these problems are being tackled all over the world, and they are being successfully solved in a variety of remarkable and often fascinating ways. But unfortunately, since they do not often make headline news, many people are quite unaware of the constructive work that is being done. Yet a knowledge of these things will be increasingly necessary as we attempt to plan our actions through the coming crucial years. The obligations that are laid upon us are not such as can be borne with dignity and confidence by men who mistrust, or do not know, their own abilities. Already we are beset on all sides by doubts and fears, and the voice of Malthus is heard in the land, counselling us to accept privation and pestilence and death as the will of a kindly Providence. The old discredited appeal to force is revived, and war is offered to panicky people as a supposed means of saving their skins. But the alternative of peaceful, productive activity exists. If we can become convinced of its reality, and can see how richly its resolute pursuit would be rewarded, it may not be difficult for us to chart a course that is worthy of our humanity.

PART ONE

WORLD ENOUGH

When we begin to think about the instruments of abundance that are waiting to be used, the first one that occurs is the land itself. There are thirty-six thousand million acres of it altogether on this planet, and at present human beings are using less than a tenth of that acreage for the production of food. To feed themselves men are actually cultivating only about one and a half acres for each person now alive. An acre and a half of good land is enough to keep one human being well fed, on a balanced diet of meat, vegetables, cereals, fruits, and dairy products, provided it yields the average achieved in a few highly developed countries. But the averages in such countries are higher than world averages, and it is perfectly plain that from the land now under cultivation the present population of the world is not getting enough to eat. Yet in fifty years' time, unless something is done about it, there will be only one acre to feed each one person. As a means of coping with the great invasion, what hope have we of increasing the productive acreage?

With nine-tenths of the total land mass still unused, it might appear that we could find enough tillable soil to support an extra thousand million people and still have enormous tracts left over. The sobering fact, however, is that the one-tenth now in use comprises just about all the easily cultivated land there is. When our ancestors invaded the American continent, they found themselves in possession of rich plains and valleys, where the deep topsoil was nourished by the right amounts of rainfall and sunshine, where the changing seasons provided perfect temperatures for each phase of planting, growth, harvest, and rest, and where all that was needed to turn the wilderness into farms was a man with a plough. Contemporary pioneers will not be so fortunate. There are no sizeable tracts left in the world from which food can be produced so easily. A goodly portion of earth's surface is either bare rock or precipitous mountain; a far larger part, comprising the Antarctic continent, Greenland, and *many smaller islands, is buried under icecaps. In the present state of human knowledge the only large contiguous areas that can conceivably be brought into productive cultivation are the deserts, the frigid zones of the Far North, and a broad band of steamy, hot country straddling the Equator.*

One may as well admit that the prospect they offer is not exactly inviting. The task of converting such areas into settled lands, where large populations can enjoy civilized life, carrying on local industries, and, above all, feeding themselves from the products of their own farms, is about as difficult as any the human race has ever encountered. Some people, of course, argue that the barriers nature has set up across these undeveloped countries can never be broken down. For what we have to deal with are extremes of heat and cold, blazing sunlight and half-year darkness, choking jungles and barren tundra. In the desert lands rain falls only once or twice a year, and then in such torrents that it rushes over the land in scouring floods, leaving denuded sand to be whipped about by the wind. The soil in the Far North is only a thin layer covering eternally frozen subsoil; in the equatorial swamps it is deep, but leached and water-logged from the perpetual downpour of the rainy season. In all these undeveloped regions the climates are ones in which human beings have never before found the energy to do much more than survive.

Yet in these very places, against almost every obstacle nature can create, the epic of the future is already being written. Although our newspapers, magazines, and radios have been too busy with the evil of the world to tell us much about it, the conquest of these recalcitrant lands has already reached the point at which its future completion is certain, provided only that it is energetically attempted. We have passed the stage where we need be discouraged by speculation, for we are in possession of living fact. Watermelons are ripening north of the Arctic Circle; cool tree-shaded parks are flourishing in desert lands where only a few years ago there was nothing but a mass of shifting sand dunes, supporting not even a sprig of tough grass; and for one of the largest of the tropical regions there is now in the world's mind a plan of scientific development that marks an entirely new era in human endeavour. The story of what has already been done in launching the gigantic battle for *more cultivable land is not only a brilliant example of man's creativeness in this hideously destructive age. It is also a proof that abundance can be produced from this planet if men want it.*

II. RESURRECTION OF THE DEAD

OF ALL the undeveloped lands which man now has the skill to make productive, the largest lie within the temperate zone, that same belt which also includes most of the fertile acres we are now using to produce our food. Dry, barren, and lifeless, deserts cover almost a third of all the land on the entire planet, which means that they account for a very large proportion of the zone in which the bulk of mankind has always lived. They sprawl over thousands of square miles in every inhabited continent except Europe, and there are even small arid regions there. Africa has the prototype of them all in the Sahara, and it has in addition a huge barren region called the Kalahari Desert on its south-west coast, along with several smaller ones. The North American deserts cover most of the south-western States; the South American ones run in a long narrow strip down the Pacific coast, from Ecuador through Peru and Bolivia and into Chile, and then spread into an enormous triangle east of the Andes. More than half of Australia is arid. In Asia the barren sands cover most of the Middle East, nearly all the Central Asian republics of the Soviet Union, and stretch on eastward into Pakistan, Tibet, Sinkiang, and up across the blank spaces of the Gobi. So far as mere size is concerned, no undeveloped regions anywhere offer so much as the deserts.

They also offer the most depressing prospect to the farmer. Some of them are barren because there is literally no soil to be found in them: they are wastes of pure rock, without a trace of nourishment in any form that a plant can absorb. Others are choked with salt, so that although the soil is deep and plentiful, it kills instead of giving life. But most of the deserts are simply dry. By and large, the land we call desert today is good land, needing only sufficient water to make it as productive as any other. The manifold problems involved in getting the water, however, are so complex and difficult that there are still many people who believe that the establishment of agriculture in arid regions is an impossibility.

Such people will admit, of course, the success of some irrigation projects which have already been completed and publicized. They have heard of Imperial Valley in California, and of the magnificent dams and dispersal systems built by the United States government and managed by the Bureau of Reclamation. They may even know how the Ferghana Canal in Soviet Uzbekistan has diverted the waters of the Syr Darya over the one-time "Hungry Steppe," turning it into rich farm lands that produce some of the highest yields of cotton in the world. But these are only isolated instances, they think, carried out by the two most energetic nations in the modern world, and not easily duplicated in others. Furthermore, they all involve using rivers.

But what of those desert regions where there is no river to be diverted? What can possibly be done in places where for hundreds of miles the only running water is the "crue," a raging flood that suddenly, once or twice a year, rushes down the eroded gullies and just as suddenly disappears in the level sands? In country where mountainous sand dunes, urged by the blistering whip of the desert wind, heave and shift like clumsy leviathans, blotting out whatever is in their path, how can men dare to build their fragile houses and lay out their fields? Where only a few inches of rain falls throughout the year, it seems hopeless to talk of finding moisture enough for crops. And what hope can there be for people like the three thousand inhabitants of the oasis of Taghit, in Algeria, who eat nothing throughout their entire lives except dates, because the soil that should feed them is ankle-deep in salt?

Surprisingly enough, the answers to most of these questions, and to many similar ones, are already known. Scientific skill and incredible amounts of patient, back-breaking labour have proved that the obstacles to settled agriculture in the desert are not totally insurmountable. Arid lands are not immutably closed to human occupation and development. Their complete conquest will be difficult, but the story of what man has already done in them is a stirring commentary on that line in the Psalms: "Thou madest him to have dominion over the works of Thy hands."

It is customary to say that there are two kinds of deserts: natural and man-made. In a sense, however, all deserts are "natural"; when man makes a desert, he does it by simply permitting the destructive forces of nature to have a free hand. It is true that in some places we are doing precisely this, and the deserts are on the march. But we have known for a long time what kinds of carelessness on our part will give nature her chance, and there is no longer any mystery about what we should do to preserve the good land we have. Everyone is agreed that the loss of any further land to the desert is not necessary.

What makes contemporary desert research so exciting is that it is finding not merely preventives, but cures. Land which was to all intents and purposes completely dead is being restored to life; and in terms of human welfare the significance of this dramatic resurrection is greater than if science had discovered a cure for cancer.

The most fascinating work is being done in the so-called "classic" desert country around the Mediterranean. From the shores of that sea the dry lands stretch southward into middle Africa, south-east across the peninsulas of Sinai and Arabia to the Persian Gulf, and eastward from the coasts of Palestine to the mountains of Afghanistan. Because huge areas, such as the inland parts of Arabia and most of the Sahara, have never been cultivated, so far as we know, we have given them a descriptive name that indicates a rather defeatist attitude on our part. Instead of calling them "virgin deserts," or some other name to indicate that man has never attempted to occupy and cultivate them, we have fallen into the habit of calling them "climatic deserts," which simply means that in our opinion the climate makes cultivation impossible. Since we cannot change the climate, we have come to accept the notion that we may as well not try to plant any crops.

The flaw in this comfortable theory is that these never-cultivated deserts have the same kind of climate as equally barren regions nearby which have, at some time in the past, been productive farm land, rich enough to provide the agricultural basis for high civilizations. The empires of Babylonia, Assyria, Greece, Rome, and a good many others all drew sustenance from regions that now are barren wastes. These bleak, infertile hills and valleys fed Hittites and Minoans, Philistines and Carthaginians; they satisfied the raging appetites of invading armies century after century, from Sargon to the Mohammedan caliphs, and from Alexander to the Crusaders. Out of these dry sands grew the food that made possible the first cities, with their trade and commerce, their laws, their knowledge of navigation. To them we owe the Phoenician alphabet, the Arab mathematics and medicine, splendid poetry in a dozen tongues, some of our finest architecture, and philosophies and religions that still satisfy the spiritual cravings of nearly half the people in the world.

How these ancient peoples managed to produce harvests in what appears today to be a hopeless desert is a question historians have often asked themselves. Until very recently the accepted answer was the old fatalistic one of climate. If in ancient times these deserts really "flowed with milk and honey," then the climate must have been different from what it is today. There must have been more rainfall; nature must have provided an environment in which crops could grow. And the land eventually died, and the great civilizations took on their shroud of sand, because nature, for no determinable reason, grew stingy.

This habit of laying the blame for whatever ills may afflict us on the weather, or fate, or some other uncontrollable force of destiny or providence is deeply ingrained in the human mind. Ignorance is its father, and laziness its mother, and no one need be surprised that the offspring of such parents is almost universally popular. So long as man can believe that what happens to him is foredoomed, he is under no compulsion to do anything about it. Fatalism, whether it clothes itself in the mud and feathers of the witch doctor or in the solemn phrases of the philosopher, owes its perennial appeal to the fact that it permits us to avoid work.

In the matter of these deserts that once were farms, however, scientific research has recently begun to remove the comfortable excuse for doing nothing. As new evidence continues to pour in, it becomes increasingly clear that the climate in the Mediterranean basin has not changed appreciably for thousands of years. Rain was as scarce in ancient times and heat as prevalent as it is now. The Canaanites, whose almost incredible harvest provoked their conquest by the hungry tribes of Israel; the Romans, whose engineering genius made North Africa the richest granary in their vast empire; even the ancient Nabataeans, learning three thousand years ago how to squeeze moisture from the desert winds to nourish their vines and trees—all these peoples and many more sowed their seed and gathered in their harvests with no more assistance from nature than farmers can expect today. And yet some fifteen civilizations and cultures were able to produce their food in the sands that now drift about their ruined monuments.

What modern research is making abundantly clear is that instead of calling these barren acres "desert," it would be more accurate to use the word "deserted." Archaeological study has shown us that the real monuments of ancient greatness are not the tombs and the triumphal arches, but rather the waterworks, the terraces, the wells, and the irrigation systems. Thousands of works of this kind have been identified, all bearing eloquent testimony to the energy ancient peoples had to expend to cope with the arid conditions. These structures put at rest the theory of climatic change; for it is evident that if the natural environment had been any better than it is today, ancient man would not have had to go to such lengths to deal with it.

More importantly, modern engineers can learn from these ruins exactly how the bumper crops of antiquity were produced. And most important of all, it appears that for the most part the methods used in the distant past can be duplicated and even improved. The magnificent harvests that supported millions of people through long centuries were not the result of magical charms, nor of mysterious resources in the ancient character which we cannot hope to find in our own. Those golden ages, like all others in man's history, resulted from practical, scientific work.

For example, the Romans, although they were governed by one of the most vicious ruling classes that ever encumbered the globe, were also the great engineers of antiquity, and it was their engineering skill and not their ruthlessness that enabled them to cultivate the desert. They went about the business very much as our most skilful hydrologists would do it today. In the first place, in areas where the water level was far lower than the depth of the average dug well, they sunk deep shafts through the rock and sand until they hit springs or underground streams. Recently modern archaeologists have begun a more or less systematic search for these deep Roman wells, and already more than two hundred have been discovered in Tripolitania, as well as numerous ones in the Egyptian desert and in other parts of Roman North Africa. Judging from the literary records of Roman occupation, it is safe to assume that there are thousands more waiting to be discovered.

When the Romans built anything, they built it to last, and their wells are no exception. All that have been found are still perfectly usable. Early in 1950, when the United Nations Educational, Scientific, and Cultural Organization (UNESCO) was drawing up plans for an international study of the problems of arid lands, one of England's most brilliant science writers, Ritchie Calder, was sent to the Mediterranean to make a preliminary report. Calder saw many of these Roman wells, and he reported that over a hundred had already been cleaned out and were functioning as well as they did two thousand years ago. When the debris of the centuries is cleaned out of them, contemporary engineers find the water exactly where the Romans found it: a further proof, incidentally, that there has been no climatic change which would lower the water table.

Far more impressive than the wells are the Roman cisterns. These were not mere storage tanks such as we are accustomed to, but gigantic man-made caverns, hewn out of the rocky core of barren hills. Like the Carlsbad Caverns of New Mexico and other natural underground wonders, the Roman cisterns were composed of a series of huge chambers, sometimes as much as eighty feet from floor to ceiling, connected by tunnels, galleries, and vaulted passageways. In their depths, water could be stored for years at a time, and taken out gradually as it was needed for irrigation.

To fill such enormous labyrinths it was necessary for the Roman engineers to devise means of catching every available drop of the scanty seasonal rainfall, and to do this they worked out an ingenious arrangement. They would first select some place where there was a natural cup in the hills as the site for their cistern. Then they would deliberately erode the hilltops, flattening them out like roofs and throwing up earthworks around the sides, so that all the rain that fell could be channelled into gutters and then down through underground tunnels into the reservoirs below. By such methods they were able to take the water that fell on one acre of the hills and make it irrigate eight acres of productive land in the valley.

Literally hundreds of these wonderful cisterns have been discovered in the Egyptian deserts, and some of them have been restored and are once more functioning. There can be no doubt that other hundreds are scattered all over North Africa, waiting only to be cleaned out and used. Such underground storage systems were still being built as late as Byzantine times. In the Negev, where Byzantine cities flourished in what is now the most desolate and intractable part of Israel, cisterns like these once conserved the scanty rainfall. When Jewish colonists near Revivim had to take cover during a bombardment in the Arab-Israel war, they stumbled into an ancient pillared cistern far beneath the surface.

Not only can men still use these old cisterns, if they will only spend the necessary energy to find them and clean them out, but contemporary engineers can build additional ones with a great deal more ease than the Romans did. Under the stress of war the engineers of the British Eighth Army constructed near El Alamein a magnificent underground shelter as their operational headquarters, quite comparable with a Roman cistern they could have had for the taking only half a mile away across the desert.

Where there was no natural site for a cistern, the ancient hydrologists used other methods of catching and utilizing every gallon of available rainfall. Normally, in desert country, water falling on eroded hills rushes down through many small runlets into what the Arabs call a "wadi," which is a large gully. Throughout most of the year the wadi is bone dry, but when the rain falls it suddenly becomes the bed of a roaring torrent, sometimes an actual wall of water eight or ten feet high. Water moving at such speed is of course completely useless for irrigation; it scours away whatever topsoil may be in its path, and when it reaches the level desert it sinks rapidly into the sand.

These intermittent streams cannot be harnessed by building the kind of huge storage dams engineers throw across perennial rivers. There is so much soil in the rushing water that in a few years the dam would be silted up and worthless. Instead of great storage dams, therefore, the Romans and all the other ancient peoples built whole series of wide, shallow weirs, not to stop the flood but to slow it down and spread it. Criss-cross channels carried part of the water that remained behind each weir into other fields lying outside the course of the river. Whenever one of these small weirs silted up, it became a new and very fertile field, and new diversion dams were built to shift the main flood in another direction.

The Romans were succeeded by the Arabs, of whom a common opinion is that they were totally destructive people who conserved nothing and built nothing. But the Arabs restored the Roman system of wadi cultivation, and built many of these small diversion dams themselves, and in many parts of North Africa agriculture flourished again, although not on the Roman scale.

Today the same methods are being used once more. Near Beersheba, in Israel, for example, Jewish settlers are using the run-off in a wadi, building small dykes to divert the seasonal flood on to their terraced fields, with each terrace spilling its extra water over into the field below. As soon as each field is flooded, the farmers plough it deeply, in order to hold as much moisture as possible, since they know this may be the only water it will receive for the rest of the year. But it is enough to produce their crops.

The constant search for water led in ancient times to some truly astonishing contrivances. One of these is the horizontal well, called a "foggara" in North Africa and a "qanat" in Iran, where it is still a common feature of village life. Starting in a dry valley, where there is no underground water to be reached by the conventional vertical well, a foggara is a horizontal tunnel dug for miles back into the hills, to tap a spring or underground river deep beneath the surface. When the water is reached, a group of lateral tunnels are dug, to draw into the main channel as much water as possible. What results is an underground river flowing in the direction that will be of most service to men. Villages grow up along the course of the tunnel, with wells and cleanout shafts being sunk at intervals, often as close as every twenty feet. In *Asia's Lands and Peoples*, George B. Cressey records that sometimes a thousand wells are supplied by one qanat, which may extend for twenty miles from source to mouth.

In Iran, and many other parts of the Middle East, and even in far-away Sinkiang, qanats are in use today, providing the only source of water for millions of people. But there are abandoned horizontal wells all over North Africa that could be used again. Having been built originally and maintained by slave labour, they fell into decay when slaves were no longer available to be sacrificed in their dark and narrow tunnels. But machinery can replace slaves, and the results that can be obtained are amply demonstrated at the remarkable experimental station of Beni Abbès, deep in the desert of southern Algeria.

Beni Abbès was once an isolated outpost of the Foreign Legion, its heavy white walls backed up against mountainous dunes on whose summits great plumes of blowing sand stood up like smoke from smouldering volcanoes. It is still isolated, but its inhabitants are no longer legionaires intent on "pacifying" the desert tribes. Today Beni Abbès houses one of several stations sponsored by the Institute of Saharan Research at the University of Algiers. It is manned by a small group of French scientists whose ultimate purpose is to show the nomads how they can cultivate their desert. They are essentially theoretical researchers, intent on solving the complex mysteries of sand and wind and heat for the pure joy of knowing, and most of their careful study of such things as sand beetles and tiny desert plants might appear to the layman to be far removed from the problems of human survival. But the reality of the garden they are cultivating, more or less in their spare time, is evident to the most confirmed nomad.

In soil that only two or three years ago was dry sand, those men and women are growing tomatoes and all sorts of other garden vegetables. The shadows of the smoking dunes fall on a small vineyard, and on orange trees that are already bearing fruit. Experimental fields of oats and barley are flourishing, giving the desert dwellers the hope of establishing basic cereal crops. Beni Abbès is eloquent proof of the theory that much desert land is good land, if only it can be watered. This particular plantation receives all its water from an ancient foggara, which runs for several miles under the dunes to tap an underground source. And, surprisingly enough, the scientists, after a great deal of study, have come to the conclusion that their unfailing spring, deep under the distant sand hills, is fed entirely by dew.

It is astonishing to be told that dew can actually provide all the moisture necessary for growing crops on a large scale, but many desert scientists today are convinced that the proper exploitation of dew offers one of the great possibilities for bringing barren lands into cultivation. Although the very fact that there is a great deal of dew in the desert may surprise many of us, travellers who have been on the Sahara report that a common sight in the early dawn is the "white dune," a mountain of sand glistening with hoarfrost. The theory is that this dew which condenses in the cold of the desert night is absorbed into the sand before it evaporates, and that it seeps down to bedrock to form the pools and springs reached by the foggara.

At any rate, a great deal of fundamental research has already been done, notably by such authorities as Dr. S. Duvdevani, who heads a special division devoted to dew research in the Israel Weather Bureau. With dew meters of his own invention, Dr. Duvdevani can measure with great accuracy the amount of moisture present in a given sample of air, and he has demonstrated that even the "khamsin," the hot and supposedly dry south wind, contains dew equal to several inches of cloud-borne rain.

Like most Israeli scientists, Dr. Duvdevani is greatly concerned with the bearing of his scientific studies on the practical problems of making the barren land of his small country productive enough to support a large population. This concern has led him to the invention of an extremely simple gadget which is proving of considerable value to his countrymen. As early as 1937 he had established, to the satisfaction of scientists, that the success or failure of many crops in that dry climate depends very largely on the presence or absence of sizeable amounts of dew at critical periods of growth, and with his meters he could estimate the exact amounts needed. He had also observed that the distribution of dew seemed to vary widely from place to place and at different times of the year. But he felt that this knowledge could be much more serviceable to farmers if they had some instrument, very cheap and very much easier to operate than his complicated machines, with which they could get a fair estimate of the dew that condensed on their fields at different seasons. If he could make such an instrument, and could persuade individual farmers all over the country to use it and send him their reports, he could draw up for the use of his government a country-wide survey. Using such a survey as a guide, the people in charge of settlement could give the new colonists much more precise information as to what particular crops they could expect to grow on their allotments, depending on their location, and what was the best time for planting.

Sometimes simple things are much harder to conceive than complicated ones. It took ten years of mulling over the problem before Dr. Duvdevani hit on a device that is about as easy to use and to interpret as Gideon's fleece. It is a plain wooden block, which the farmer is instructed to set up at a standard height in the open air, from sunset to sunrise. Along with the block he receives a book of life-size photographs of similar blocks, each holding a different amount of dew. Some pictures show many large drops, some show few tiny ones, and on some of the pictured blocks there is only a trace of moisture or none at all; the farmer is asked simply to find the one that corresponds most closely to the appearance of his own block. Each day at dawn he is asked to look at his block and report the number of the most similar picture, along with the date and place of his observation. In making up the book, of course, Dr. Duvdevani has carefully measured the weights of dew for each of the types of drop distribution shown in the photographs, so that it is a simple matter for him to work out a fairly accurate estimate of seasonal variations for each locality from which the farmers send him their records.

As soon as these wooden blocks and picture books were distributed, some highly significant information began to come in. As might have been expected, crops in the great rift that cradles the Jordan River and the Dead Sea get very little assistance from dew in the months between April and June, when they need it most: at Jericho the condensation in June is practically nil. But in contrast to this negative information, the reports showed that at this same season there are uncommonly large amounts of dew in the coastal and hill country, ranging up to 7 mm. at Ramot Ha Shavim. This is a far greater amount than people in well-watered country are accustomed to; it is enough, in fact, to nourish a number of crops even when there is no other source of water for them.

This work represents an important contribution to agriculture in arid lands, and is one that could doubtless be used to advantage in many other desert countries. Meanwhile, Dr. Duvdevani has gone ahead with theoretical studies that require the use of his most accurate instruments. One of the most interesting of his demonstrations is that in any given body of free air, whether it is nearly dry or nearly saturated, the highest concentration of moisture seems to occur always at a height of about one metre above the ground. This discovery gives a clue to one way of utilizing dew more effectively for crop production; it also serves to explain one of the strangest devices ever invented by ancient farmers.

In the Negev, in what Biblical writers called the Wilderness of Zin, there are places where the landscape is dotted, as far as the eye can reach, by geometrically arranged mounds of flint pebbles, about a metre high. According to the archaeologists, these mounds were built by men three or four thousand years ago, probably by a people called the Nabataeans, but only recently have they discovered what was their purpose. In many of these mounds have been found the roots and stumps of ancient vines and trees, and it is evident that the function of the mound was to condense dew out of the atmosphere and cause it to percolate down to the roots.

The many references to dew in the Old Testament make one wonder if the ancient Israelites may have found and used some such mounds as these. Certainly the Psalmist's praise of God as One who "turned the rock into a standing water, the flint into a fountain of waters" might have been written by a man marvelling at the inspiration which prompted such an ingenious invention. And when the author of Deuteronomy writes that the Lord enabled the people of Israel to "suck oil out of the flinty rock," the modern reader wonders again if this poetic phrase refers to olive trees planted in dew mounds.

Contemporary Israeli scientists are not only, like the French in Algeria, giving serious study to dew and all its possible uses, but they are using the phenomenon of condensation in another way in their struggle against one of the most formidable obstacles to desert reclamation: salt. On brackish, heavily salted land they plough deep furrows, and then cover the entire field with sheets of transparent nylon. Since the infra-red rays of sunlight pass through the nylon, fresh water is evaporated from the salty earth and condenses on the cold nylon furrows. The nylon used in this method of obtaining fresh water, incidentally, is itself a product of the desert. It is made by a fermentation process from the castor-bean plant, which is indigenous to the Mediterranean countries. It has long been known as the source of that plague of childhood, castor oil, but only recently have scientists at the famous Weizmann Institute at Rehovoth discovered that they can produce plastics from it.

Since most of the industrial materials now made from petroleum can be made from fermentation products, even including such things as rubber and aviation spirit, the humble castor bean may actually provide the basis for considerable industrial development in a country that has very few mineral resources. At any rate, so great is the faith in its possibilities that the scientists at the institute have developed a variety that grows even without irrigation. Such a cash crop would be of tremendous importance to farmers in extremely difficult country like the Negev.

Meanwhile the battle against salt goes on. The classic story of man's struggle against this bitter enemy is the widely publicized experiment at Beth Haravah, known to Americans through the motion picture, "The House in the Desert." On the shores of the Dead Sea, some of the most heavily saline soil in the world was patiently flooded and reflooded and flooded again, until the deadly minerals were leached out of the topsoil down to a level below the depth of ordinary root systems. Beth Haravah, although it was a minor epic of man's persistence, was a small-scale experiment, and it was forcibly abandoned when, at the partition of Palestine, the land was handed over to the Hashimite Kingdom of Jordan and the Jewish settlers moved back to Israel. Whether the lessons learned there can be applied elsewhere on a sufficiently large scale to justify the enormous expense and labour is an open question, depending primarily on whether fresh water, in great quantities, can be brought to those places most in need of desalting.

Such a place is the picturesque oasis of Taghit in Algeria, north of Beni Abbès, where three thousand people exist on a diet of water and dates because they can grow nothing to exchange for other food. The water from their spring is potable, but it does contain some salt, and through the centuries this salt has poisoned all their land. Whether the plight of these people can be relieved is a very serious question, but certainly it is one that cries out for solution. There is some talk of trying to grow tobacco to exchange for food, but there is not much certainty that it can be grown successfully. What Taghit needs above all else is a good supply of fresh water.

It is possible that some relief could be found if methods of desalting now in use in Israel could be introduced. Jewish scientists have devoted much of their energy to this problem, and have perfected several workable methods, in addition to the use of nylon sheets already mentioned. One of the most ingenious is the solar-distillation plant, a glass frame shaped like a prism, in which the heat of sunlight evaporates the salty water, leaving the minerals deposited on the bottom; then the moisture that has evaporated into the air inside the frame condenses on the colder glass at the back and trickles down into the runlets. This contrivance can produce some ten and a half gallons of pure water a day, and larger models with greatly increased capacity could doubtless be built.

The limitation of both the nylon-sheet and the solar-distillation methods, however, is that the product is distilled water, so far in rather limited quantities. A method of desalting that offers much more in the way of practical, large-scale work such as irrigation is found in the ion-exchange plant at Rehovoth. Here only the deadly minerals are removed, by the simple and comparatively inexpensive method of passing saline water through successive beds of resins (amberlites) in granular form. Percolating through the first layer of resinous material, the water loses its sodium; in the next, the hydrochloric acid is taken out. The amount of mineral removed at each step can be controlled, so that the water can be desalted to whatever degree is necessary. The end product, therefore, is not distilled water, but water with sufficiently small amounts of minerals that it can be used for drinking, or washing, or irrigation.

Although the particular method of ion exchange that is in use at Rehovoth was worked out at the Weizmann Institute to remove specific contaminants occurring in waters in Israel, Dr. Ernest D. Bergmann, the Scientific Director of the Institute, has explained that the general idea of ion exchange through the use of resins did not originate with his staff. Indeed, the first synthetic resin capable of effecting such a change was produced as long ago as 1858 by a German chemist named Eichhorn. The most important single step in the long history of work in this field was taken in 1935, when the British chemists B. A. Adams and E. Leighton Holmes produced some new and much more effective synthetics. They laid the foundation for the work of chemists who now "tailor" synthetic resins for the purpose of removing one or another specific mineral. Since then many ion-exchange systems have come into use, principally for the purpose of removing calcium and sodium, and thus softening hard water; the largest water-softening plant in the world is said to be the one owned by the Metropolitan Water District of Southern California, which treats four hundred million gallons of water daily.

The special problems of removing noxious minerals from brackish desert water, however, have been carried furthest at the Weizmann Institute. A good bit of work had been done in various places during the Second World War, when the constant danger of shipwreck and of forced landings of aircraft on the ocean made it important to find, if possible, some small and portable device that would enable survivors in life rafts to supply themselves with drinking water. After the war, a group at Harvard University undertook to adapt some of the methods used in these little devices to the much larger scale necessary before the method could be of value to agriculture. The chief problem was one of reducing costs. When these Harvard experiments showed promising results, the work was taken over by the Weizmann Institute, and a pilot plant was begun.

The principal credit for the method now used at Rehovoth is usually given to the late Dr. Chaim Weizmann, the distinguished first President of Israel. Almost unique among the statesmen of the world, Dr. Weizmann was a practising scientist, whose contributions to chemistry had made his name famous long before his lifelong dream of an independent Jewish state had been achieved. Seeing him at work with his resins, sweetening the brackish waters for the use of his people, one could recall how an earlier leader of Israel once solved the same problem.

> "And when they came to Marah, they could not drink of the waters of Marah for they were bitter . . . And the people murmured against Moses, saying, What shall we drink? And he cried unto the Lord; and the Lord showed him a tree, which when he had cast it into the waters, the waters were made sweet."

The purifying tree does not apparently grow in modern Israel, or at least if it does the botanists have not yet discovered its properties. But with Weizmann's resins the waters are being made sweet. The method involves considerably more effort than Moses had to expend, but it is just as effective.

In 1948 the pilot plant at Rehovoth was producing two thousand gallons a day, and at that time the construction of larger ion-exchange plants, with a sufficient capacity to supply irrigation systems, was prevented by the tendency of the resin beds to clog. Now, however, a method of cleaning the resins has been worked out, with such success that the Rohm and Haas Company of Philadelphia has recently perfected devices which it claims will produce pure, salt-free water in quantities sufficient for large-scale factory use, either from the ocean tides in such rivers as the Hudson, or from streams that have been contaminated by industrial waste.

Whether even such devices could bring the possibility of healthy living to the inhabitants of Taghit is still in doubt, since they have the problem of poisoned soil as well as saline source water, but certainly their relief seems to have been brought a step closer. The ultimate solution of their problem, as well as those of many other desert communities now struggling against the corrosive effect of minerals, would seem to depend not on one method or device, but on a combination of different methods now being tried out in widely scattered places.

All over the Mediterranean lands the manifold problems of desert reclamation are being tackled in isolated, local projects, often with a success that amazes the uninitiated. In place after place, land that to the unpractised eye was completely worthless, its one-time fertility apparently gone for ever, is being reclaimed and made to bear crops. Take as an example the desolate valley of the Guir in Algeria. In the first century of our era, when it was explored by Romans, it was watered by a perennial river. You will find in the elder Pliny's *Natural History* an account of that exploration, which Pliny borrowed from the official report sent to Rome by the commander of the expedition.

The explorer was Suetonius Paulinus, a military and political figure who had been sent out as propraetor of Mauretania in A.D. 42, and who is better known to us as the father of Caius Suetonius Tranquillus, the historian of the twelve Caesars. According to Pliny, this man was the first Roman commander who actually crossed the Atlas Range and "advanced a distance of many miles beyond it." There were three things that struck the hardy Roman about the country he explored. He noticed first that the higher peaks of the Atlas were covered the year round with snow and that this snow fed "the river called the Ger" which flowed southward toward the desert. "But he also states," says Pliny, "that the regions at the base of the range are filled with dense and lofty forests of trees of an unknown kind, with very tall trunks remarkable for their glossy timber, free from knots, and foliage like that of the cypress except for its oppressive scent, the leaves being covered with a thin downy floss, so that with the aid of art a dress material like that obtained from the silk-worm can be made from them." There were also, according to Suetonius' report, forests along the Guir, which "swarm with every kind of elephant and snake."

In the first century, in other words, the Guir was a perennial river, fed by the unfailing snows of the Atlas, flowing down through country where natural vegetation protected its banks, holding moisture and preventing erosion. Centuries after Suetonius's visit, the forests that protected the great valley were cut down by the Arabs and once deforestation was begun, the inevitable cycle of destruction set in. Today there are no animals, for there is no forest to shelter them; in the valley of the Guir is a barren wadi, coming in flood four or five times a year with such vehemence that the hills are eroded completely bare and the rushing water is lost in the sand. Most of the valley is a flat, grey expanse, whose surface is packed as hard as concrete. To the untrained eye the prospect of raising crops in such land looks as hopeless as planting seeds on a macadam highway.

Yet at a place called Abadla in this desolate valley, sixty miles west of salt-cursed Taghit, there are burgeoning trees, luxurious gardens, and fine wheat fields. This seeming miracle has occurred because engineers of the French "Society for Rural Amelioration" discovered that what appeared to be solid rock was actually a deep layer of silt, brought down from the northern mountains by the flood and deposited in this level basin, to be packed down and baked by the desert sun until it seemed impervious. But with heavy tractors, soil breakers, and disc ploughs, they were able to break up the rock-like crust. And underneath it they found rich, damp soil.

Once the fertility of the valley was proved, and its reclamation made feasible, the government moved ahead with plans for large-scale development. Already tests have established the "reclaimability" of more than fifty thousand acres, and experts on the ground believe that when the whole valley is surveyed and studied, plus a smaller one nearby, the total cultivable area will run as high as 125,000 acres. As fast as the land is tested and prepared for cultivation, it is divided into units of a thousand acres each and turned over to native Arab farmers on a collective farming basis. Each collective is supplied with a heavy tractor, a light tractor, and other necessary machinery and implements. In return for the use of the land and machines the collective farmers pay to the administration one-fifth of their produce. The money thus earned will pay for all the work of reclamation, including reforestation and the building and upkeep of the traditional Arab system of shallow dams to control the seasonal floods, and will also provide the funds for extending desert reclamation to many other parts of the Sahara.

Colonel Quenard, who as Military Commandant of the territory of Aïn-Sefra has the ultimate supervision over the project, believes that on fifty thousand acres of this rich land it will be possible to produce enough grain to supply the entire population of the Sahara. When the whole project is completed, a diversified agriculture is planned which will not only give a balanced diet to the inhabitants but furnish considerable exports as well. The result in human terms is that nomadic tribes are becoming communities of settled farmers, and achieving a standard of life that even their Prophet did not dream possible.

Elsewhere the search for water and uncontaminated soil takes different forms. Burg-el-Arab, for example, is a man-made oasis in the Egyptian desert, which, under the shrewd direction of Dr. Milad Bey, has expanded since the war to include twelve hundred acres, and it is still growing, thanks to a promotion scheme as clever as an American advertising campaign. When Dr. Milad arrived at Burg-el-Arab after the British in the Second World War had reconquered the area, he found that the small experimental station that had existed before the war had been completely obliterated, the fields and orchards destroyed, and the whole place gone back to the desert. His job was to rebuild the station and expand it, but the funds that had been given him were as limited as those usually assigned to scientific work; if he had used them in the customary way, Burg-el-Arab would probably still be smaller than it was before the war.

Scientists being, in the main, earnest fellows whose chief concern is to get on with the job, the usual way to tackle a problem like this is to house themselves as quickly as possible in temporary barracks, or even tents, give up all social pleasures, even refusing to admit any visitors to their encampment, and devote themselves day and night to what strikes the layman as tedious, backbreaking, and singularly dull work. When the time comes to ask for more funds, they stop their precious labour long enough to write up long and detailed reports, filled with the scientific terms that are so meaningful to them but are often pure Greek to their readers. Then they wait, hoping that someone will read their reports and be stirred to send along the necessary money for them to carry on.

Milad Bey was clever enough to know that if he did this, the likelihood was that he could never get Burg-el-Arab on its feet, for the simple reason that the officials who would control his purse strings would never see the dramatic possibilities that he could see. With a truly inspired gesture, he proceeded to take the entire amount that had been given him and build a small but magnificent guest-house as the first structure at Burg-el-Arab, complete with every comfort one could ask for. Around it he laid out a garden, and here he planted a bewildering variety of trees and flowers and vines, with small plots of vegetables beautifully laid out and tended. Nothing was spent on the slow and tedious work of large-scale afforestation or on the colourless labour of research. All the money he had, and more importantly, all the water, went into that beautiful guest-house and its luxuriant garden. Then, when all was ready and the funds were exhausted, instead of writing a report, Dr. Milad issued invitations to his sponsors to come and visit Burg-el-Arab.

The officials of government bureaux, the VIPs, even Cabinet Ministers came and were dazzled by the spectacle of that tiny corner of desert in unbelievable bloom. They did not need to be told what possibilities lay hidden in the bare sands that surrounded this oasis; all they needed to do was to look. The result was that the funds Dr. Milad and his associates needed for their real job were immediately forthcoming, and today twelve hundred acres are under cultivation. The reclamation work is financed by the government, but the land is divided into small plots and farmed by individuals or family groups. The principal product is olive oil, and the trees on an acre and a half supply enough to give several families a far higher standard of living than they ever enjoyed as nomads.

The creation of man-made oases is one of the surest ways of bringing cultivation into the desert, and wherever it is possible it is one of the easiest. What is necessary, of course, is to drill an artesian well. Drilling to the necessary great depth is fabulously expensive, especially where the heavy equipment and the necessary oil has to be transported over great distances through roadless desert. But at many places not too far inland from ports, the cost is not prohibitive, especially when one strikes such a source as the one recently tapped by a deep well in Tunisia. South of Gafsa, at a place that has been named Castilia, a new man-made oasis is being developed around a deep well that flows over 150,000 gallons of fresh water in a day. Such a water supply is worth all it cost to reach it.

It was largely such artesian wells as this that made possible the flourishing Italian colonies that were established in North Africa before the Second World War. Since those colonies were planted solely for the benefit of the Italians, and gave no help to the native peoples, whose plight was actually made worse than it had been before, they were doomed to eventual failure. As a matter of fact, one of the tragedies of the whole struggle against the desert occurred when the Italians were conquered by the British; for the native population, in blind and vehement jubilation at the defeat of the hated colonists, rushed out before the British could stop them and cut down or destroyed over a million trees that the Italians had planted. To the nomad those trees were a symbol of a way of life that had curtailed and frustrated all his nomadic habits without giving him any mode of existence that could replace it.

Despite this tragic and pointless destruction, however, many of the Italian olive plantations survived; so many, in fact, that in 1950 Tripoli exported olive oil for the first time since the days of the Romans—five thousand tons of it, much of which came from trees planted only twelve or fifteen years before that had somehow survived the wrath of the nomads. This great production, coupled with the memory of the unthinking violence, provides a profound lesson for all governments concerned with desert reclamation. It is a lesson that appears to have been learned by most of the official agencies now actively at work, for they all seem intent not on squeezing the nomad out of his desert but rather on providing him with the means of earning a livelihood through settled cultivation and teaching him how to do it.

This provision and this teaching embrace far more than supplying fresh water, preparing soil, and furnishing seeds and equipment. For one thing, the nomad must be taught to control his domestic animals, especially his goats. These wretched animals are the scourge of all vegetation. Instead of cropping grass, they tear it up by the roots, and by stripping the leaves and bark from small trees they can completely destroy a young forest overnight. Hardly less destructive are their masters, whose constant need for fuel prompts them to scour the desert in search of any woody substance, living or dead, that will burn.

Laws prohibiting these practices can be enforced only when the nomad has alternative methods of satisfying the appetites of his goats and his own need of fuel for warmth and for cooking. That workable alternatives can be provided has been amply demonstrated by all those governmental agencies that have carried out successful reforestation in the desert countries. The native peoples are perfectly willing to burn oil, provided they have the means of buying it, and they will keep their goats off planted areas if they can realize the value of the plantations by sharing in them.

In places where once-flourishing forests have been destroyed, the control of goats and fuel gatherers alone has sometimes been enough to produce the necessary reforestation. On the island of Cyprus, hills that until recently were denuded are becoming clothed once again in forests of cedars, cypresses, and pines, not because any new trees have been planted but simply because new shoots from the old root systems have been given a chance to grow. Even more surprising is the rejuvenation of the ancient "Enchanted Forest" in the Valley of Sharon. The mighty oaks that grew there in the Middle Ages were cut down by the Crusaders, and through all the succeeding centuries goats have effectively prevented any regrowth. But when the Israeli stopped the practice of allowing untethered goats to roam at will through the valley, within three years the centuries-old roots were sending up new sprouts.

Under truly desert conditions, however, natural forces cannot produce a forest by themselves, and human beings must take a hand. In many parts of the Mediterranean basin men are doing precisely this, creating plantations and forests on land that would appear doomed to eternal barrenness. The establishment of a man-made forest on a sand dune is a fascinating operation. First, a whole area of many acres is marked off with lattices in five-yard squares. Then these squares are outlined with closely planted dess, a coarse, wiry, native grass, which is one of the few plants that will take hold in the blowing sand and dig in. Once the dess is established, it forms a minor windbreak, giving some protection to the tiny acacia trees that are planted in the hollow squares. These little seedlings, incidentally, are given further protection by planting them, not on the surface of the sand, but in small hollows, so that until their roots begin to grow they do not receive the full force of the wind.

Within a short time the roots of trees and grass begin to mat, and soon a good cover is holding down the sand. In ten years such a planting as this becomes a real forest, capable of supplying fuel, so long as it is cut sensibly, and at the same time forming a permanent windbreak that prevents the sand from blowing. Forests like these have been planted at many places in North Africa, to form green belts around the cultivated croplands, and Ritchie Calder has described them as "woods as green and gracious as an English park." The work of dune fixation is constantly being extended, particularly by the British Administration in Tripolitania. For those who may still have doubts about the feasibility of desert reclamation, the important thing to remember is that such afforestation is proceeding, not on the basis of hope but upon proved experience. We know that human beings can change much of the desert land of the world into food-producing farms because on thousands of acres they have already done it.

But since scientists are always aware of possibilities beyond what they have already accomplished, the realization of many projects is still in the future. One of the most tantalizing facts that has been revealed by desert research in Africa, for example, is the existence of unbelievably vast lakes of pure water deep under the desert sands. One of these underground, fresh-water seas is the so-called Albienne Nappe. The stratum in which it lies outcrops in the Atlas Mountains, and it runs for hundreds of miles out under the Sahara, at very great depth, where, at widely separated points, deep drillings have proved it to be a virtually inexhaustible source of water. A similar underground lake of tremendous dimensions is said to exist deep under the Libyan Desert of Egypt, and scientists believe that plentiful supplies of fresh water could be found under most of the deserts of the world, if only it were possible to drill deep enough.

Deep drilling is of course technically possible: private companies no longer hestitate to bore two or three miles into the earth's surface in the hope of finding new oil-bearing strata. But mere water cannot pay back the fantastic cost of such operations, and until those costs are reduced the underground water reserves in the desert countries cannot be tapped. This means, in effect, that the solution lies in having an abundance of cheap energy on the spot, for drilling and pumping, in order to avoid the long and costly haul of imported fuel. What are the chances that such cheap and abundant energy may be produced in the desert?

There are two or three possible sources of such energy that may in the future be exploited. One is the process of nuclear fission, if its industrial possibilities can be more fully explored and sufficient quantities of lightweight, easily transportable fuel made available. A more likely source of energy for use in the desert countries is solar radiation, for it is in the desert that sunlight is most constant and intense. As to the possibility of using it, Eugene Ayers of the Gulf Research and Development Company has summarized the situation as follows: the concentration of solar energy for the purpose of producing heat, and thence power, has been proved feasible; it is simpler to produce and far safer to use than the energy released by nuclear fission; and it is inexhaustible, whereas our supplies of uranium are definitely limited. But desert scientists admit bitterly that they cannot hope to capture the unlimited energy that beats down upon the dry sands until the physicists give some of their time and attention to the development of large-scale equipment for capturing and using the sun's power.

In the meantime, those who are striving to turn the desert regions into habitable, productive farm lands must get along as best they can with such means as they have at hand. With those means they have already proved that deserts in general are not unconquerable. The whole of North Africa is coming alive again after centuries of somnolence, and farther east the new nation of Israel is providing a model of land reclamation that can inspire desert dwellers throughout the world. With lucerne grass growing knee-deep in the Negev, where the rainfall is less than four inches a year; with strawberries ripening in the deserts of Egypt, and rich wheatlands coming into harvest in Algeria; with the dunes being halted in Tripoli and olive orchards once again producing their precious oil in quantities for export—surely the time has passed when one can have doubts about the ability of modern man to use productively the vast areas of arid land that are at present lying waste and barren.

The great limitation of contemporary desert research is its isolated, local character. What is needed most seriously is some general pooling of scientific knowledge, some organized and co-ordinated attack on the desert lands on an international scale. If the scientists at Beni Abbès, Abadla, Taghit, and the other settlements in Colonel Quenard's vast section of Algeria could exchange their information and discuss their still-unsolved problems with Dr. Bergmann's group at Rehovoth, for example, there is little doubt that both would profit. Dr. Duvdevani's wooden blocks and photographs could be usefully employed, it would seem, by nomads-turned-settlers in many parts of Tripoli, Egypt, and the countries farther east. Scientists from countries far away from the Mediterranean have much of value to contribute as well; and there is many a desert scientist, struggling in some half-forgotten outpost to stretch his meagre funds far enough so that his work can be finished, who could use some of Dr. Milad Bey's skill in public relations. Just as Israel, as has been often said, could become a veritable laboratory of demonstration for the whole of the desert country, so it should never be forgotten that from Cyprus to Afghanistan, and from Teheran to the Gates of Hercules there are men and women, agricultural stations and experimental farms, laboratories and classrooms that are daily adding to the store of scientific knowledge facts that could be used to advantage in Israel, as well as in many other places.

It would certainly seem possible to set up an international clearing-house through which information and technical skill could be exchanged. In fact, one of the United Nations agencies has already made some concrete moves in that direction. UNESCO, in which fifty-nine member nations co-operate in educational, scientific, and cultural projects, is in process of establishing an international council to study the whole problem of the arid lands of the world. The general public has heard of UNESCO's work mostly in connection with such matters as the world-wide battle against illiteracy, the Book Coupon plan through which war-wrecked libraries are being restored despite the dollar shortage, and the attempt to make widely known and understood such information as the Universal Declaration of Human Rights. But in its science division, UNESCO is vitally concerned with the problem of increasing world food supplies and has been for several years at work on it, sponsoring international conferences, granting fellowships, and establishing its four Field Science Co-operation Offices, one of which is in Cairo and serves the Middle East generally. The fact that UNESCO has begun a definite survey of the problems of desert agriculture offers great hope for the future.

What can be the potential of these desert lands, if and when enough men make up their minds to conquer them? How many people can they support, with how much food? The question is of course not answerable, in any final sense, for it is not mere acreage but the labour of human beings that is the primary factor. The fallacy of Malthus's famous theory that increasing population automatically means lower standards of living lies precisely in his failure to realize that man is a producer as well as a consumer. Within limits, one can say that the more people there are in a given area, the more food that area can be made to produce, provided of course that they have the means of production.

But since contemporary work has proved that man can revive agriculture in dead lands, and since many of his methods can be applied also to "virgin" deserts where there has never been any cultivation, we can get some clue to the potential resources of the desert lands by studying the populations some of them supported in ancient times. Calder points out that Tunisia, for example, with a population of a little over three million in 1950, must have been inhabited by two or three times that many people in Roman times, since it would have required in the fourth century some seven million workers to keep going all the ancient irrigation systems that have been discovered and to till the fields we know were under cultivation, in addition to the merchants, food handlers, shippers, and all the other dwellers in the great cities. Modern Iraq is a wasted land that barely supports five million people, most of them in gruelling poverty, yet at the height of the Arab civilization, under Harun-al-Rashid, it was a veritable paradise in which thirty million people lived in conditions approaching luxury. Even in the dry desert of the Negev, where agriculture has always apparently been a seriously difficult undertaking, archaeologists have already uncovered the remains of six Byzantine cities, in each of which from ten to twenty thousand people once lived. The leaders of the modern state of Israel believe that they can develop the Negev into a homeland for at least a million human beings.

Similar figures can be cited for most of the once-productive regions in the Mediterranean basin. The great exception is Egypt, whose population, confined to the valley and delta of the Nile, has tripled within the present century, and now stands at over twenty million. Even the fabulous wealth of the Nile cannot support such numbers in anything more than a poverty that cannot even be imagined by people who have not seen it. To save herself, it appears that Egypt must develop her great expanses of desert.

As for the areas that have apparently never been cultivated, it is now known that many of the methods used in reclaiming "deserted" land can be applied to them as well. In thinking of them, it would be well to remember that the main Sahara, whose fringes, only, have been touched, is nearly as large as the entire United States, and that the Arabian peninsula is the size of all the states east of the Mississippi. The whole Arabian interior is waiting to be developed, and it has wadis and underground streams in abundance, and just as many natural sites for cisterns as any other place. As a matter of fact, some are already in existence. Along the old caravan route from Bagdad to Mecca, at intervals of a day's march, there are a whole series of cisterns and wells which have been in continuous use for over a thousand years. Queen Zubaida, the wife of Harun-al-Rashid, had these watering places built early in the ninth century to lessen the rigours of the pilgrimage to Mecca which devout Moslems felt obliged to make.

Many of the other great deserts of the world need only human labour, guided by the scientific knowledge that is already available, to bring them under cultivation. There seems little doubt that an enormous portion of the arid third of our land can be turned to good account toward solving the problems soon to be created on this planet by the great invasion of our progeny. If we are willing to spend the necessary money and energy, the problems themselves may disappear.

III. THE CROPS MOVE NORTH

TWENTY-FIVE YEARS AGO it was generally agreed that agriculture had reached its northern limit. Man had extended his cultivated fields to within a few degrees of the Arctic Circle, and he could never hope to go farther. Beyond these outposts lay the frozen land, where nothing could grow and where man himself could never be more than a hard-pressed wanderer. No matter how numerous or how hungry the human race might become, most authorities were willing to write off the arctic and subarctic regions as a dead loss, so far as civilized habitation is concerned. Because of the intense cold that creeps downward from the pole, sending its chill into the very heart of any living thing, the Far North was considered doomed to eternal barrenness.

It was inevitable, however, that sooner or later the northern country would attract the attention of a hungry world. Its very size makes it impossible to ignore it, for although it is smaller than the desert regions, still it covers more than a fifth of the entire land of the world. Geographers have set no prescribed limits around that portion of the globe they call the arctic regions, but a very convenient one is provided by the 32° mean annual temperature line, north of which average year-round temperatures are lower than the freezing point of water. This assumed boundary runs a wavy course around the upper part of the planet. Where warm ocean currents swing up toward the Arctic Circle or beyond, it retreats toward the pole, so that Norway, Iceland, most of Sweden and Finland, the southern tip of Greenland, and about one-fourth of Alaska lie south of it, outside the region that in general has been considered too cold for agriculture. On the other hand, in continental areas that receive no benefit from ocean currents, it may extend down to the fiftieth parallel or below, as in Canada and in eastern Asia. The arctic regions, therefore, include about three-fourths of Alaska, a very large part of Canada, the Lapland portion of Scandinavia, and an enormous area in both the European and Asiatic parts of the Soviet Union. Greenland and the other islands that are covered with icecaps can be left out of account.

If you study on a map the physical features of this huge region, it looks positively inviting. Here are mountains and valleys, mighty rivers and almost limitless plains, and the incredibly long coast lines of three continents pushing out into the ocean and enclosing deep and spacious harbours. Seeing its promise, men began to wonder if they could not find some means of combating the bitter cold that made the arctic regions uninhabitable. During the past twenty-five years interest in developing them has grown steadily, and out of all the discussions and the trials and errors one conclusion has emerged clearly: a settled agriculture can be established in the arctic regions, but it must be a specifically arctic agriculture, growing most of the same crops that are cultivated in the temperate zone but using different techniques especially adapted to the different climate.

Little has been done to develop such an agriculture in Canada or Alaska, and for very good reasons. Canada's small population is quite adequately supported by the temperate part of the country. The same is true of Alaska, whose farming population is concentrated in the Matanuska and other southerly valleys, where they are able to use much the same methods as those employed in Minnesota and other temperate regions with comparable climates. Magnificent work has been done in the northern states of the U.S.A. and in the western Canadian provinces in developing hardy varieties and pushing temperate-zone agriculture to its northerly limits. But so far, neither Canada nor the United States has felt any particular pressure to settle the extremely cold parts of its territories, nor to develop the truly arctic agriculture this settlement would require. Doubtless the time will come when they will do so. The strategic importance of Alaska will require larger and larger settlements farther north than the present ones, and more attempts will be made to supply these settlements with food grown locally. As more mineral resources are discovered farther north, both in Alaska and in Canada, farming populations near the mines and industrial centres will be increasingly needed.

But up to the present, almost all the work of developing a genuine arctic agriculture has been done in the Soviet Union. Again, there are very real and cogent reasons. In the first place, 47 per cent of the entire land area of the Soviet Union lies north of the 32° mean annual temperature line. Furthermore, in this slightly less than half of the country are rich deposits of coal and other minerals and the largest amount of standing timber in the world. The Soviets need these products. But an even greater incentive to develop a successful arctic agriculture was found in the attempt to open and operate a northern waterway connecting the cities and ports of European Russia with Vladivostok on the Pacific. The establishment of agricultural settlements in the frozen tundra began as an adjunct to the accomplishment of this four-hundred-year-old dream. In order to provide for heavy traffic through the Arctic Ocean, it was necessary to build coaling stations, weather observatories, and ports all along the route. Larger and larger resident populations were needed to mine the coal, process the lumber, and handle all the other products that make up much of the cargo carried on the seaway, as well as to service the ships. The great influx of settlers into the north country required the shipping in of enormous quantities of food. But there were no railways, and the air lines that ran north from points along the Trans-Siberian Railroad could not carry the whole burden. It is not surprising that from the beginning of work on the sea route, the Soviet government has encouraged in every way it could the development of local sources of food.

The difficulties were legion. The first farmers quickly discovered that the bitter cold was but one, and by no means the most formidable, of the obstacles they must overcome if they intended to live and to grow food crops in the frigid region, and these obstacles exist in Canada and Alaska as well. To begin with, there is an extremely short growing season; in most parts of the Arctic it lasts no more than a hundred days, and in many places barely seventy days elapse between the spring thaw and the first killing frosts. This factor in itself would seem to make a diversified agriculture impossible, because so many standard food plants in the temperate zone require longer than this to sprout, grow, and produce a harvest.

But a further obstacle is raised by the fact that the sun, when it does come back to warm the earth after the long arctic winter, seems determined to do a thorough job of it and shines night and day. Plants do grow faster under this constant bombardment of energy, but it is a feverish growth that sometimes does more harm than good. It is somewhat as if you tried to speed up the growth of children by stuffing them with food while allowing them no sleep.

Another, and very serious, difficulty men have had to overcome is the condition of the soil itself. Throughout most of the northern regions the soil is poor, so poor that even in temperate zones it would require the most careful feeding and handling to make it productive. For one thing, it is highly acid; for another, underneath it there is an almost impenetrable layer of perpetually frozen subsoil. It is only the top that thaws in the brief summer; through the icy layer underneath, as impervious as solid rock, drainage is next to impossible. This frozen subsoil is not only a hazard to agriculture; it is also the primary obstacle to building settlements where would-be farmers can live. If you use it as a base for foundations, when the buildings are heated it will thaw out, and down will come your house or your factory. If you drill tunnels through it and lay pipes, any water or sewage sent into those pipes will freeze.

Finally, there are the polar winds, which blow almost without ceasing throughout the long winter months, often with such force that neither man nor beast can stand against them. The winds die down during the short summer months, so that crops are not whipped out of the ground, but from the farmer's point of view they have already done their damage, by denuding the frozen fields of the protecting blanket of snow.

When you add all these natural obstacles together, it would seem as if the frozen north were one place in which the establishment of settled agriculture must remain for ever a dream, and a very fanciful dream at that. Yet men have moved into the northern country and have succeeded in overcoming all these difficulties and others. By 1943 they had brought into cultivation nearly a million acres, and in doing it they had learned techniques that will make easier the subjection of other millions. They are harvesting barley, wheat, rye, and oats; they are eating their own home-grown potatoes, vegetables, and fruit; they are even raising musk-melons and tobacco. Kohlrabi, which they can grow successfully, provides them with more vitamin C than they could get from lemons imported from the south. And having found that full-sized fruit trees were frozen to the marrow by the polar winds, they are now gathering cherries and apples and pears from shrubs that creep on the ground.

The accomplishment of these difficult tasks is the result of a patient, step-by-step attack against the barriers set up by nature. Conditioning everything else is the question of time; for the most serious struggle has been the one to bring crops to maturity in a shorter season than crops have ever been produced before. This problem has been tackled in a number of ways. The farmer's race against time begins in the winter, long months before he can hope to plant a seed or set out a tiny seedling. His first battle is against the wind; his problem is to collect as much snow as possible on his fields and hold it there, to conserve the maximum amount of heat in the soil. This was not so difficult as it may sound, for snow fences and windbreaks have long been used in other parts of the world, and the principles were well known.

But although it is necessary to hold the snow on the earth during the winter, it is equally necessary to remove it as fast as possible when the sun returns. In more leisurely climates farmers can wait for the sun to melt it gradually, but when one has only from seventy to a hundred days of growing weather, every day counts, and nature has to be hurried. In the Chukotka Peninsula, the great arm of land that swings out from Siberia toward Alaska, the farmers spread a thick layer of ashes on the snow. Since dark colours absorb sunrays that are reflected by the white snow, this covering of ashes makes the snow melt faster. As a result, the fields are cleared and ready for working two full weeks ahead of the normal schedule. Those fourteen days added to the growing season can make all the difference between success and failure with the crops.

The same problem has been solved slightly differently by the farmers around the Russian town of Vorkuta, in the Pechora Coal Basin, the northernmost coalfield in Europe. They also build elaborate shields to keep a deep cover of snow on the earth during the winter, preventing the topsoil from freezing as hard as it would if left bare. Lying there during the long dark months, the snow tends to pack and freeze, so that it is all the more resistant to the first wan rays of the returning sun. But at the first sign of spring the Vorkutan farmers take their ploughs into the fields and plough the hard-packed snow, breaking it up into as small fragments as possible to hasten the thaw. Then they sprinkle on a good coat of coal dust from the nearby mines. By such means they are able to clear their fields a full month earlier.

Using similar methods, farmers all over the northern country have been able to hurry up natural processes, and to stretch the precious "summer" a few days or weeks. But even the full month of extra growing time achieved at Vorkuta was not enough. Potatoes, for instance, were planted and grew, but they were killed by frost in August, before the tubers on their roots had time to mature. The ground does not freeze that early, but at night the temperature of the air often falls below the freezing point, killing the rather delicate leaves and forestalling any further growth of the tubers. The summer night frosts last only about two hours, but that is long enough to put an end to the hope for a potato crop.

California orange growers might have suggested the smoke pots they themselves use, which protect their trees against occasional frost by throwing up a screen of warm smoke around the orchard. But at Vorkuta there is no wind in summer, and the smoke would not spread down over the ground to protect the low-growing potatoes. Nevertheless, those farmers were determined to produce their own tubers; they finally called in some scientists, who solved the problem in a rather ingenious way. Taking a tip, perhaps from the old proverb about fighting fire with fire, they proceeded to fight cold with cold. They constructed sprays with very fine atomizers, and when the frost came on they drenched the delicate potato plants with water. As each tiny droplet froze in the cold air, it gave off heat, and this heat was absorbed by the leaf on which it fell. Three or four such sprayings during the two-hour period of danger were enough to keep the plants alive. When the temperature of the outside air rose with the return of sunlight, the thin film of ice melted and the leaves took up again their task of drawing in nourishment for the maturing tubers. By the time longer and more serious frosts set in, the potato crop was ready to be harvested.

Despite such efforts as these, there still remained many plants whose cycle from seed to harvest could not be completed in the time available, and various other methods were adopted to speed them up. Naturally, one of the first to be tried was the old-fashioned trick of planting seeds in cold frames long before they could be started in the open ground. This method has long seemed practical to vegetable and flower growers, who work with a reasonably small number of seedlings, but the labour of transplanting field crops is an enormous undertaking. Nevertheless, under the cruel necessity of time, farmers in the Far North carry out this labour every year; many even plant their potatoes in frames and set out the sprouts by hand.

Another trick of outwitting the clock is the old one of soaking seeds in warm water before planting, a simple device that has added several vegetables to the northerners' diets. Onions, for example, consistently failed to mature in the Narym territory in Siberia, until in the early 1940's Kuzma

Litvinchuk and his associates at the State Selection Station tried soaking the hard little seeds for eighteen minutes in water heated to 122° F. When these seeds were planted they sprouted in one-tenth of the normal time. With such a head start, the onion bulbs matured and were harvested before the ground froze.

A variant of this method is one called "Jarovization," said to have been invented by that same Professor Trofim Lysenko whose theories concerning inheritable characteristics have lately provoked great controversy. He began by partly saturating seeds in water, to start germination. Then, after germination had begun, he treated his seeds very much as nurses treat premature babies: that is, he simply kept them at a constant temperature for periods ranging from five to thirty days, depending on the kind of seed, protecting them against the rigours of alternating heat and cold they would have found in the earth. After this period of "incubation," the sprouted seeds were planted. The result, according to the British writer H. P. Smolka, who visited the Soviet Arctic in 1936, was a speeding up of the whole life cycle, as well as a general strengthening of the plant. Winter oats, he reported, when submitted to this treatment and sown in the spring, not only produced their fully ripened grain earlier than ordinary spring-sown oats, but yielded a 30 per cent larger harvest as well.

For many difficult plants the solution to the short growing season has been found by plant geneticists, who have worked tirelessly at their crossbreeding and selecting in order to produce hardier strains. These do not necessarily mature any faster than the older varieties, but their greater resistance to cold enables them to keep growing longer into the autumn, and thus they can produce their harvest before the ever-deepening frost finally destroys them. Most of the northern farms are now developing their own hardy seed stocks. From them such unlikely crops as sugar beet and even tobacco are now growing in open fields and yielding harvests almost equal to those in the south.

Many interesting techniques of farming have been devised in the attempt to establish agriculture in the Far North. Winter wheat, for example, seemed for a long time an impossibility in the Siberian steppes. No matter how hardy the strain, and no matter how carefully the seeds were planted at the end of summer, when spring came few seedlings were alive. For a good many years, all the scientists who looked into the problem assumed that the cause of this destruction was simply the intense cold of the northern winter. Since they could not warm up the climate, and since they could not apparently breed a variety hardy enough to withstand the cold, they decided that farmers would have to plant wheat in the spring and make the best of it, even though winter wheat, if it could survive, would produce a better harvest.

Finally, according to the story, the ubiquitous Lysenko appeared on the scene and proposed a novel idea. It is one that indicates that Professor Lysenko, whatever his reputation as a controversial theoretician, must be at any rate a fairly practical dirt farmer. Perhaps, he suggested, it is not the low temperature that kills the seedlings; perhaps the real damage is done by the autumnal winds, whipping at the tiny leaves and breaking the sprouts, and also by the shifting and heaving of freezing soil, which would of course tear the little root systems. If this were the cause, why not try to give the seedlings some protection against these two hazards, and see if they could not stand up against the cold? In short, why not try "stubble planting"?

"Stubble planting," which is a common technique in the United States and elsewhere, is simply a method of sowing the grain with disk seeders in the stubble left from the harvest of the spring-sown grain. For two reasons it seemed promising as a defence against arctic hazards. Since the ground is not broken up by any cultivation, it remains tightly packed; there are no pockets of water to freeze and push against the new roots. The stubble, taller than the little newly sprouted seedlings, protects them against the blast of the wind, and also helps to hold a warm blanket of snow on the fields during the long winter.

Stubble planting has been given a good test since it was first introduced into the Arctic in 1942, and its success seems assured. In the bad winter of 1944-45, when temperatures fell lower than they had in fifteen years, and when wheat sown in the old way was killed all over the northern steppes, stubble-planted wheat survived and produced yields about equal to the average for the whole Soviet Union. So far this technique has not increased the actual areas in which wheat can be grown; but it has made possible the planting of winter wheat where farmers had formerly depended on grain sown in the spring. And this means more food in the world, for winter wheat yields more, and it also gives the farmer more time in the busy spring planting season to devote to his other crops.

One of the most interesting techniques is the one that has given the northern settlers a supply of fresh, tree-ripened fruit. For quite a number of years the introduction of apples, cherries, and other fruit trees into the tundra was considered an impossibility. It is one thing to protect with stubble and snow the diminutive sprouts of winter wheat. But no one could devise a practical way to keep a tree warm; reaching up into the icy air, its great body seemed of necessity exposed to the full terror of the polar winds, and there is no fruit-bearing tree that can survive such an attack. But where nature fails, man often succeeds by changing nature. In this instance man has fashioned a new shape of tree, and from it he is gathering fruit in the Arctic.

The new creation begins life as an ordinary tree. It is set out when it is a year or two old, but immediately the main trunk is cut back very close to the ground, in order to stimulate the growth of side branches. As these branches develop, they are trained to grow horizontally, spread out like a circular fan all around the trunk and fastened down with wooden pegs, in somewhat the same way as French horticulturists make their espalier trees stand flat against a wall.

The whole tree is kept just high enough to prevent the fruit from actually resting on the ground. During the winter it is comparatively easy to protect these prostrate trees from the wind by covering them with leaves or straw and snow. Thus protected, they are said to be able to withstand temperatures of almost sixty degrees below zero on the Fahrenheit scale.

By and large, the cultivation of field-grown crops in the Far North has not involved any totally new concepts of agriculture. Most of these special techniques are simply extensions and adaptations of methods long practised in the temperate zone. The difference is often one of degree. Manure, for example, has been used to enrich the earth for countless generations, but never in such quantities as are heaped upon the soil of the tundra. Near the upper end of the Yamal Peninsula, where the Gulf of Ob reaches out to the latitude of Point Barrow on the northern coast of Alaska, farmers spread on their fields as much as eighty tons of manure to the acre, an amount to stagger the imagination of most farmers. In such places the thick blanket of manure almost takes the place of soil. It protects the seeds and seedlings from both the cold air above and the cold ground beneath, feeding them at the same time.

It is by such methods that what used to be considered the natural boundaries of agriculture have been widened to include several hundred million unused acres in the arctic regions from which farmers can now hope to produce food. Of course some plants that are grown outdoors in milder climates have resisted all efforts to make them survive in open fields. Fortunately, they are mostly the vegetables, which are ordinarily grown on a much smaller scale, and which the northern farmer can raise in frames and hothouses. Here he grows his tomatoes, his lettuce and cauliflower, and even rhubarb, by very much the same methods he would use in the temperate zone. The chief thing he has to remember is to cover his frames with mats from time to time, to create artificial "nights" during those weeks in summer when the sun shines twenty-four hours of the day.

At the Markov Agricultural Station in the Chukotka Peninsula, the staff have discovered that this is especially important in handling seedlings that are destined for transplanting. Cutting off the sun for certain periods each day actually shortens the growing season, for when they are transplanted into open fields these seedlings develop into mature plants much more quickly than those that are left fully exposed to the midnight sun while in the frames. The Markov Station group reported in 1947 that they were handling all their field-grown cabbages in this way.

Arctic hothouses sometimes exhibit typical solutions to local problems. Many of them are dug into the ground, in order to give them protection against the polar winds. But putting a heated building underground, in the perpetually frozen soil, has involved the construction of double insulated walls, for the builder has not only to keep the cold out of the hothouse but also to keep the heat away from the surrounding earth, lest it thaw and cave in. H. P. Smolka has described the hothouses at Igarka as "built of solid brick and lined with wooden beams, the doors fur-lined, and all the fissures carefully padded with cotton wool, seaweed, and textiles." These Igarkan indoor gardens are only half buried in the earth, but as one goes farther north they are built progressively deeper, until on the far northern islands their heavy glass roofs are level with the ground.

In supplying the necessary heat, various ingenious methods are used. Where local industries produce a surplus of hot water, this is pumped through doubly insulated pipes in the frozen subsoil and circulated through radiators. This method is used, for example, at Amderma, in the Nenets National Area around the Gulf of Ob, where the local power station supplies the hot water. Inside their fur-lined doors the Igarkan hothouses are heated with old-fashioned clay stoves. But on Dickson Island, off the northern coast of Siberia where the Yenisei empties into the Arctic

Ocean, the inhabitants have no industries on which they can draw, and little fuel for stoves. Nothing daunted, they have taken the bitterest enemy of their comfort, the polar wind, and harnessed it to produce heat for them. Windmills convert the icy blasts into electricity, and this not only gives warmth for houses, laboratories, and hothouses, but in winter it creates as well the artificial sunlight necessary for plant growth.

That isolated polar station now supplies itself completely with fresh vegetables, and even with eggs and poultry, the year round. At the present time hothouse cultivation is practised at nearly all the stations along the entire shipping route from Archangel and Cape Cheluskin to Chaun Bay and Wrangel Island, and right on around to Kamchatka.

Most of these outposts are supplied as well with produce shipped up from more southerly, but still arctic, farms. This is not so simple as it sounds; it poses an unusual problem to which the shippers have found a most ingenious solution. Since the harvest comes just at the end of the brief northern summer, when the cold is already sealing off all the means of transportation, it was necessary to find some way of keeping farm products fresh through the long winter, so that they could be delivered in the following spring. Deep freezing would seem the most appropriate solution nowadays, but Smolka reported in 1937 how, lacking quick-freeze equipment, they had already solved the problem by a method apparently invented on the spot. Instead of gathering only the edible portions for storage, they uprooted the entire plants, and stored them in large boxes filled with carbon monoxide. Here the plants "slept" through the arctic winter and, according to Smolka, 80 per cent of the food products were perfectly fresh when they were taken out for shipment in the spring. Life on the shores of the Arctic Ocean may lack some of the amenities we take for granted in the temperate zone, but the notion that settlers must live in igloos and subsist on a diet of walrus meat has been completely exploded.

What of the future? Are the achievements of far northern agriculture merely interesting experiments, carried out on a small scale at terrific cost in human effort, or do they point the way toward the opening of vast tracts of hitherto unproductive land? It is all very well to learn that radishes and turnips are growing in open fields hundreds of miles north of any place they had grown in 1925, or that scientists at an isolated polar station now drink milk from their own cows, and boil eggs from their own chickens in water heated by the energy of icy winds. But what bearing has such information on the world problem of supporting a population of more than three thousand million?

The initial conquest of the North has not been easy, and its development as a homeland for millions of people will not be easy, either. But that areas of extraordinary size are waiting to be utilized by man, and that these regions can be the setting for thriving communities, sizeable industries, and above all for productive farms seems to be beyond question. With approximately one million acres already yielding satisfactory harvests, the time has passed when arctic agriculture can be dismissed as small-scale experimentation. What has been done in parts of Siberia and northern Europe can doubtless be duplicated in hundreds of other localities in those countries, in Alaska, and in the great plains of arctic Canada. For the important thing is that methods of agriculture specifically adapted to arctic conditions have been worked out, and techniques whose original development cost great effort can be duplicated with comparative ease.

That these frigid regions can ever produce large quantities of food for export seems unlikely. But that is hardly the question. The point is that dwellers in the northlands can supply their own needs, without draining off precious food from the rest of the world. The cost of production so far is high, but it is not as high as the cost of shipping it in, especially in quantities sufficient for the support of industrial centres. Furthermore, as men learn better how to cope with local conditions, production costs will inevitably decline.

How large a population could live comfortably, busy and well fed, in the arctic and subarctic regions is a matter of pure speculation. Even estimates of usable land vary wildly, and little confidence can be put in any of them for the simple reason that there are still tremendous areas about which next to nothing is known. But in thinking about the potentialities, one fact we can profitably keep in mind: where nature has thrown up virtually every obstacle one can think of, human brains and human labour have created productive farms. The fact that on almost a million acres in the Far North men have already succeeded in raising good crops is less significant than the fact that in the arctic regions as a whole there are millions upon millions of acres on which no one has yet tried. By itself, the North cannot solve the world's food problem. It can however, make a sizeable contribution.

IV. THE HABITABLE TROPICS

Of all the undeveloped regions of the world, those with the highest potential productivity are probably the tropical lands of Africa and South America. A great deal of work, involving many different approaches to the problem of land development, has been undertaken already in various countries of Africa, and much of it will be discussed at some length in succeeding chapters of this book. But richer in possibilities than any African territory is the enormous expanse in our neighbouring continent through which flow the Amazon River and its numerous tributaries. As a case history in what mankind can now achieve in the exploitation of new territories, it is also the most significant.

The unique importance of the Amazon Valley to the future well-being of humanity is not its resources, plentiful and varied as they may be, nor even its great size, which is nearly as large as that of the United States. What entitles it to first consideration is that in approaching its development we, as human beings, have taken on a new dimension. The plan known as the Hylean Amazon Project is in many ways unique in human history, and the more one studies its implications, the more clearly he sees emerging from the shadows of the future the outlines of a new phase in human civilization.

What is called the Amazon Valley, or Amazonia, is not merely the valley of the great river itself; it is the whole territory from which the rain that falls on one-fifth of the South American continent, funnelled down through dozens of streams and rivers, is finally poured into the Atlantic Ocean. It begins in the Peruvian Andes, only eighty miles from the Pacific, and its boundaries sweep in two semicircles toward the east, one swinging south through Bolivia and Brazil and the other circling northward to include parts of Ecuador, Colombia, Venezuela, and the three Guianas. Thus Amazonia is not one country, in the political sense, but a region administered in parts by nine different governments, three of which are European imperial powers.

Although it has been partially and haphazardly explored, and small colonies have been established at one point or another, the natural barriers have so far prevented any large-scale settlement. It is easy enough to sail up the main river; but to penetrate the rank jungle pushing down to the water on either side, to cope with the myriad insects and the debilitating diseases of the tropics, to find the edible fruits and avoid those that drip with poison, and most of all to endure the suffocating heat of the central valley—all these rigorous necessities have proved too much. Large parts of Amazonia have never even been seen except by the small primitive tribes who have always lived there, as full of fear as jungle beasts and just as merciless to any intruder. All these circumstances have prevented any real occupation of the region by a large, food-producing population. Despite the fact that some two million people are scattered around over the enormous territory, it is still virtually empty.

Yet its possibilities are impressive. Among all the river systems of the world, the network that drains this vast land is the most extensive, carrying a larger volume of water than the Nile, the Mississippi, and the Yellow rivers combined. The Amazon itself is unrivalled as a waterway; ocean-going vessels can dock at Manaos, one thousand miles up-river from the mouth, and steamboats can carry passengers and cargoes a further thirteen hundred miles to Iquitos. Many of the fifty or so major tributaries are also navigable by steamboats, and smaller craft can penetrate almost the entire area. This is possible because, although the source of the Amazon is 12,000 ft. above sea level, the river falls 10,000 ft. in the first four hundred miles. Throughout the remaining three thousand miles of its journey to the sea, it ambles along through the plains, making an average fall of only one foot in every mile and a half, as wide, deep, and gentle as any river pilot could desire. That is the first fabulous resource of Amazonia: water, in almost unlimited quantities, for power and for transport.

The second most obviously valuable feature is the forest, surpassing in profusion and variety the natural vegetation of any place in the world. When Louis Agassiz visited the Amazon, he was so dazzled by the wealth of trees that he decided to see just how many different varieties he could identify in a half-mile square. He counted one hundred and seventeen. In this seemingly interminable forest are rubber trees and rosewoods, balata wood and Brazil nuts, palms, acacias, bananas, oranges, tree ferns, figs, and scores of others—some whose properties are known and some that so far are only names in the botanists' catalogues. Not all of them are useful, and at present the valuable and the worthless are so commingled in the rank exuberance of the jungle that both lumbering and cultivation are difficult if not impossible. But because forests can be cleared, and commercially desirable trees segregated into manageable plantations, the jungle that now seems a barrier to civilization is really a potential asset of incalculable worth. It will of necessity provide much of the economic basis for future communities.

In addition to the trees, a bewildering variety of other plants flourish in the Amazon region. Standard food crops like beans, potatoes, coffee, tomatoes, and barley are cultivated by the sparse population that already lives there, to say nothing of such exotic plants as pineapples and cherimoyas, and the tonka beans that are used to flavour tobacco. Curare, quinine, cocaine, and rotenone are only the most familiar in a long list of drugs derived from plants that grow wild in many parts of the country.

Animal and fish life is abundant, but so far only the faintest actual knowledge of their real extent and usefulness is available. Somewhat the same thing is true of mineral resources: there are indications that they are abundant, but up to the present no competent geologists have ever made any systematic explorations. As to the climate, in the central valley it is bad—for people not supplied with air-conditioning equipment—being hot and humid and cursed with the unvaried monotony of rain and yet more rain. On the upper prairies and mountains, however, that cover at least a third of the whole area, people accustomed to the temperate zones can live and work quite comfortably.

Here, then, is an area about which men know only enough to be sure of one thing: if it can be developed, it can become one of the richest settings for productive human activity in the world. In its more than two and a half million square miles, there is living space for tens of millions of people, and from all indications they can find the means of providing themselves with a high standard of living and of making genuine contributions to the welfare of the rest of us. All this, of course, depends on how humanity sets about the task of colonization.

In the past, undeveloped lands that seemed so richly endowed as this were opened up by the classic method of conquest. A strong nation would simply send its troops into the new country and put it to fire and sword, driving out or enslaving the weaker people who already lived there. It was stupid, cruel, and extremely wasteful, but men behaved in this manner because they did not know any more sensible way to get what they wanted and needed.

Even after they had conquered, they continued to waste themselves and the resources of their new possessions, again largely because of sheer ignorance. The colonists who were sent to Virginia to mine gold died like flies and died penniless, because nobody had taken the trouble to find out that there was no gold there to be mined. Worse still, nobody bothered to find out what might be there, so that it was a pure accident when somebody discovered that the Indian crop, tobacco, could be made the basis for an economic life.

Today it seems incredible that people would attempt to settle in a strange country with no knowledge whatever of the land, the climate, the plants and animals, the minerals, and the water supply. And civilized people are beginning to realize that we need to find some better method of developing a new country than the antiquated one of permitting a strong nation to seize it by conquest. To the questions of how to open up a potentially rich area and how to make it support a large population, the most civilized answer to date is given by the Hylean Amazon Project.

The name is somewhat misleading, for it suggests that the scheme is concerned only with the "hylean," or heavily wooded, section of the main river, whereas in actuality it embraces the entire region. Even the word "project" is something of a misnomer, since we tend to think of a project as a co-ordinated activity in process of being carried out. Really, the Hylean Amazon Project is only a plan, a roughly sketched outline; little more, in fact, than a dream. But it is such a dream as men have not dreamed before.

The story begins as recently as 1946, when a Brazilian biologist named Paulo Carneiro drew up a resolution. He proposed to UNESCO that it set up an International Institute of the Hylean Amazon. On the surface there may seem nothing remarkable about such a resolution, but there are a number of things about it which seem to grow only more significant the longer one considers them.

The fact that it was a proposal to study the problems of developing Amazonia is not greatly original. Many people in the past have had similar ideas, and some of these have been tested in practice. From time to time one or another of the nine governments concerned has projected some work for the improvement of its own territory, such as dredging a harbour or draining a swamp. Commercial companies, interested in one particular product of the country, have invested outside capital and have tried to build up their own holdings. But most of these enterprises have come to very little, largely because their success depended on the completion of other projects that were never begun.

Finally, the idea dawned that this immense region cannot be successfully developed piecemeal. It is one geographic unit, and if it is to be made a productive homeland for a large population, it will have to be tackled as a whole. This does not mean, of course, that the whole enormous task must be attempted overnight, with literally hundreds of individual projects being set in motion simultaneously. What it does mean is that a master plan must be drawn and that each individual undertaking must be so designed that it will fit, without any dislocations, into the over-all pattern. This is the first achievement of the Carneiro resolution: it proposes that the problems of Amazonia be considered as one problem, and that an institute be set up to study the area as a whole and to plan for its development as an integrated unity.

Furthermore, this Institute is to be an international one, set up and supported primarily by the nine governments most immediately concerned, but under the sponsorship of a large section of the entire world. Now this is a totally new conception of how the human family should make use of its resources. It assumes that the earth, with all its riches and all its heartbreaking and backbreaking difficulties, is the proper concern of all men who live on it, and not merely of different national groups. Implicit also is the recognition that what happens in a native village on a remote river in Bolivia is intimately related to events in a port city thousands of miles away in Brazil, and indeed to the flow of life in Chicago or Warsaw or Singapore. This resolution asserts that humanity has grown up to the point where we can understand this, and that we can face up to a task together, as one world-wide community, working co-operatively for the mutual benefit of us all. When it is a matter of extending our common civilization into new and untried regions, urged by the necessity to feed our rapidly growing species, we are all involved.

But the Project goes further than this. The job of the Institute is to study and to plan—a provision which again brings a new element into the story of human attempts to subdue a wild country. For what is contemplated for the Amazon region is not merely development, but *scientific* development. For the first time in the history of human occupation of new lands, it is proposed that men go ahead on the basis of what they can know, rather than on what they hope, or believe, or wish. In other words, they must set about this job exactly as any scientist undertakes to solve a new and challenging problem.

Before there can be any discussion of founding colonies, the first essential is to know the country far better than it is known at present. The best way to start, in order to avoid the wasted effort of duplication, is to gather together every scrap of useful information already recorded. Then scientists trained in a dozen disciplines must be called on to fill in the gaps in that knowledge. They will have to map the terrain, explore the resources, study the people who are already living in the Amazon to see what can be learned from them about how to survive in tropical jungles; they will need to examine the soils, to find out which food and industrial crops will grow there, and equally important, which ones will not. There are literally hundreds of unanswered questions about this equatorial country, and until scientists supply factual answers to them, attempts at large-scale settlement would be only courting disaster.

Finally, when all the evidence is in—or at least all that can reasonably be obtained in advance of actual occupation—the plan for the development of Amazonia can be drawn up. The hope, of course, is that this plan will again be undertaken as an international, co-operative effort, and that it will be drawn in terms of what is scientifically practicable and desirable. At the very least, it should be possible to establish one enterprise in terms of its relation to another, to place industries with regard to their access to both supplies and markets, and to avoid the costly and tragic mistakes that have so often occurred in new communities in the past.

To carry out such an undertaking is not going to be easy. Besides all the natural obstacles in the country there are human difficulties in the project itself: national rivalries, the reluctance of governments to spend money on long-range programmes, the hesitation of all nations to assume collective responsibility for matters of human welfare. Private investors tend to be impatient of any supervision, and to get annoyed if the success of other enterprises should require changes in their own money-making schemes. And as for being guided by its collective brains instead of by individual passions, humanity has so far shown little inclination even to try it.

Yet in spite of all this the International Institute of the Hylean Amazon has been launched, and has already made some definite progress. UNESCO, contributing more than mere sponsorship, undertook one of the fundamental tasks: the assembling of whatever useful facts may be already recorded. This is not so easy as it may sound, for although there are numerous eye-witness accounts, they are not to be found by consulting a few standard works of reference. The basic material is scattered all over the world, in both public and private collections. It exists in the letters of a trader, written to relieve the boredom of life in a village up-river; in sailors' yarns and soldiers' complaints; in the hastily scribbled notes of an explorer; in a local priest's reports to his superiors; in diaries, in official records, in steamship logs, in folk tales, in gossip. The hundreds of people who have jotted down some fact worth our knowing have been of many nationalities and tongues, and they have looked at the strange world of the tropics from a variety of interesting backgrounds. But their observations can be of great value, if only they can be made available to present-day scientists. This UNESCO is attempting to do, and the work of collecting, translating, and organizing all this vast amount of material is under way.

As for the Institute, it has also begun its work. In starting the programme the governments and the scientists have been very sensible: they have not tried to do the whole thing immediately. Instead, they decided to start with a few small, carefully planned scientific studies in limited areas. Whatever these exploratory surveys may turn up can be fitted later, like pieces of a huge jigsaw puzzle, into the total picture of the whole region. Meanwhile, those little group studies are like the pilot plants that industry builds to test a new process before launching a whole set of factories.

The first group of scientists was sent to study the valley of the Huallaga River in Peru, one of the tributaries of the Amazon. It was headed by the Mexican zoologist and entomologist, Dr. Candido Bolivar, who, in addition to managing the whole undertaking, had the special responsibility of studying what animals, birds, and insects now live in the valley, what they can contribute to man, and what useful foreign species might be introduced. Along with him, UNESCO sent the Peruvian botanist, Dr. Ramon

Ferreyra, to answer the same questions about plant life: Dr. Edwin B. Doran, Jr., from the Department of Geography of the University of California at Berkeley, to record such basic information as the size, shape, and condition of the land itself; and from Ecuador, an anthropologist, Dr. Anibal Buitron, to study the few people who already live in the Huallaga Valley, and to find out how they could be given a new mode of life that would help them instead of hurting them.

In addition to these four distinguished scientists from four different countries, the government of Peru sent along the director of the Military Institute of Geography in Lima, Colonel Gerardo Dianderas, as well as Professor Pedro Weiss from the Faculty of Medicine of its famed National University of San Marcos in Lima. To assist in the work the Peruvian government also recruited some dozen students and graduates of the university and the Department of Agriculture, a group of young people brimming with ideas and energy, and gave them a chance at practical fieldwork under the direction of specialists for which any student of science would give his eyeteeth.

It is not hard to imagine what contributions such a group can make. As a matter of fact, they came back with the sober conclusion that this one isolated, thinly populated valley, hidden in the eastern folds of the Andes, could support a population of between a million and a million and a half. "There are in the valley wide areas of land suitable for cultivation, largely untouched by man," writes Dr. Bolivar in his report to UNESCO, "and the valley itself constitutes a major reserve which could easily be opened up to civilization and might become the source of immeasurable wealth . . . once an adequate system of roads has been built." Dr. Doran adds, in matter-of-fact Yankee tones: "No major soil erosion is visible, soil fertility is apparently little impaired, and general destruction of the forest has not occurred." Even Dr. Buitron, in his long and careful "Ethnological Survey of the Valley," is impelled to *include a description of the magnificent richness of the land, characterizing it as "a region offering great possibilities for colonization, by reason of its vast fertile fields, its gentle slopes which are sheltered from floods, its rich vegetation and animal life, its climate, which although hot is far from being unbearable, and its excellent salubrity."*

Such phrases may sound like the enthusiastic stories of explorers in the New World several centuries ago. But these men are not adventurers, trying to persuade kings to pay for another wonderful journey into the wilds. They are scientists, who report with equal clarity the need for roads and the danger that those very roads may open the valley to plunder. Native methods of logging, for example, have already caused the virtual disappearance of several valuable woods, and Dr. Bolivar issues a serious warning that unless strict controls and sound reforestation policies are enforced from the very beginning, a large farming population would quickly find itself in danger, not only from lack of timber, but also from the resulting floods, erosion, and general barrenness.

One grave threat to large-scale agriculture was discovered in the locusts that periodically descend on the fields, and the scientists point out quite correctly that this is a problem which cannot be solved locally, but requires the co-operation of many nations in Central America and the northern part of South America. But as proof that the starting points of locust swarms can be found and locusts can be controlled, they cite another international effort in which Great Britain, France, Belgium, and other countries, working together, have made great headway against these destructive insects in Africa.

As a matter of fact, locust control has been successfully carried out in a number of places. During the Second World War one of the greatest achievements of the Middle East Supply Centre was just such a campaign. This Centre was established by the major Allies in order to prevent, if possible, the dislocation of the Middle East economy, and to ensure the food supplies of some eighty million people. One of the problems was the destruction caused by locusts, which have ravaged fields in that area since the time of the Pharaohs. The campaign that held these insects in check during the war years was a brilliant example of what can be done when a group of nations carry out a programme of common action based on regional planning. For the locust-eradication programme, Great Britain and the United States furnished supervisors and trained technicians, a thousand troops who did much needed fieldwork, and four or five hundred vehicles. The Soviet Union provided the specially equipped aeroplanes and trained pilots needed for spraying the breeding grounds. The governments of Saudi Arabia, Iran, Ethiopa, Eritrea, and the Sudan, in all of whose territories breeding grounds were located, gave their full co-operation, as did those of Iraq, Egypt, Palestine, India, and Syria.

The work of the Middle East Supply Centre was so effective that locusts were not a serious pest for several years, but it was abandoned as soon as the war ended. In the spring of 1951 Iran was once again threatened with the worst locust plague in eighty years. The insects were breeding in an area of some two thousand square miles in the southern part of the country, and there seemed a real danger that when the eggs were hatched swarms of locusts might denude most of the cultivated fields of Iran. The Iranian government appealed to the United States. Through the Point Four programme of technical assistance, aeroplanes and new insecticides were dispatched to Iran within ten days, and they arrived in time to destroy a very high percentage of the eggs. It is evident that the locust problem in the Huallaga Valley could be met just as effectively.

The reports of the Huallaga investigators are crammed with information, some of it merely interesting, much of great value. There are frequent observations about the abundance of edible fish, especially of a local variety called the paiche, which surpasses even the codfish in the amount of protein it furnishes. But here again there is a warning. The local inhabitants take fish by the ruinously wasteful methods of poisoning or dynamiting the streams. If their resources are to be shared with a larger population, they will have to be persuaded to use more economical methods. Dr. Bolivar mentions crocodiles, turtles, and manatees, all valuable for food as well as for commercial products, as being also in need of protection.

One of the most curious bits in the zoologist's report is the account of a strange cave-dwelling bird which the natives wrongly call an owl, but which Dr. Bolivar, being a conscientious scientist, is careful to identify as *Cipsolomorphus* of the family *Steatornithidae.* These birds build their nests high up on the walls of caves, and when their eggs are hatched they fly out at night-time like bats to hunt food for their young. All through the night they keep flying back to their nests bringing oil-bearing seeds to feed their offspring. These little creatures have such voracious appetites for the oily tit-bits that before long they become literally balls of fat, so stuffed they cannot move. At this point, the native Huallagans obligingly remove them from the nests, render out the fat in deep frying pans, and thus supply themselves with one of the basic necessities. The fat from these little birds is not only useful as a protective oil smeared on tools and weapons; its food value is greater still, for it has all the nourishment of butter yet is much more easily digested. With protection, these cave birds might become an important source of one of the essential foods.

The value of beginning a settlement project with such scientific studies is obvious. When and if colonists attempt to settle in the Huallaga Valley, they will know, better than newcomers to a strange land have ever known, exactly what they are up against. They will live under the jurisdiction of governments that have been able to decide, in advance and on the basis of observed fact, what enterprises to encourage, what restrictions must be imposed, and how to tie in the life in this locality with the wider endeavours of the whole Amazon region. If the Hylean Amazon Project is carried out as it is intended, we shall have no "lost colonies," no gold miners stranded in country where gold is non-existent, and no farmers hopelessly struggling to raise rice in land unfitted for any cereal crop but wheat.

One important development is already under way in the Huallaga Valley. At Tingo Maria, the principal town, scientists at the Co-operative Agricultural Experiment Station are engaged in extensive tests of a new type of rubber tree. Their eventual object is to establish large plantations in the valley, which is generally considered the most promising area in Peru for their cultivation. The tests have been so successful that in 1951 two U.S. Department of Agriculture experts who are helping with the work, Howard F. Allard and William Mackinnon, drew up for the Peruvian government a plan by which more than 6,000 acres can be planted with high-yielding stock produced at the Station. Peru at present produces only about 1,500 tons of rubber a year, all from wild trees. The projected plantings of cultivated trees would increase the annual production by about 2,400 tons of dry rubber.

UNESCO's scientific expedition which has focused attention on the Huallaga Valley is only the first of many similar studies that will need to be made in all parts of Amazonia if the whole enormous area is to be brought into the scheme of human activity. A few others have already been started, and in them, too, there is the same interesting spectacle of men and women from different countries pooling the results of their specialized studies in a variety of sciences. Since the most pressing problem, so far as the long-range food supply of the world is concerned, is a detailed study of the soils, much is being done, and much more needs to be done, in the fairly new sciences of pedology and ecology, whose business is the analysis of soils and the mutual relationships of organisms and their environment.

There is also, in all the proposed work of the Institute, the same interest in the native peoples, the same respect for their integrity and concern for their welfare.

Whether the Hylean Amazon Project will ever be carried out in all its magnificent detail is an open question. No one can predict, at this point, how far the interest of the various governments will continue, nor whether they will furnish the relatively small sums necessary to finance a systematic study of the whole region. Until many more surveys are completed and a great deal more evidence is in, it is too early even to draw up the over-all plan, much less to decide specifically what highways are to be built, which resources exploited, and a thousand other matters.

But the significance of the project is apparent, and will remain even if the work should never be carried out. For it has given a blueprint for the opening of new lands better than any we have had before. The remaining large undeveloped areas of the world are all difficult regions which will require the most careful, intelligent work men are capable of. In all of them some method must be found of enabling different kinds of scientists to understand one another's purposes and results; to co-ordinate their efforts, so that botany can aid anthropology, and the archaeologist's knowledge of an ancient waterworks can be utilized by the modern engineer; and to direct the specialized scientific curiosity of each into channels where it can contribute to the total solution of the problem.

Furthermore, the question of diverse national interests is not confined to Amazonia. As we have seen, and shall see again in later chapters, there are other potentially productive regions whose development is at present prevented because men have drawn national boundaries where there is no natural boundary. Some form of co-operative, international planning, in terms of the whole geographic region, will have to be found, and it will have to be one that provides for the fullest use of all the regional resources without causing any nation to suffer at the hands of its neighbour.

For solving these knotty problems, we now have in the Hylean Amazon Project an instrument, or at least the model of one, that can be varied, enlarged, and improved in the light of local conditions. Like most great conceptions, it is clear, practical, and in the final analysis so simple one wonders why it was never thought of before. But if men really intend to make the fullest possible use of what cultivated land is left, they would do well to think of it again. Working together in such projects, we can produce the food for our survival. More importantly, we shall be taking a forward step in the evolution of the human community.

V. THE LAND NOBODY PLOUGHS

Scattered all over the globe, in every country where agriculture is already firmly established and even highly developed, there still remain areas of unused land. Taken one by one, these areas are small, at least by comparison with the great empty spaces of desert or tropics, or with the one-fifth of our planet's land surface in the frigid zone. But when you add them all up, there is in the temperate zone an astonishing amount of potentially rich farm land which nobody at present is ploughing.

We may leave out of account the millions of acres that are given over to grazing. Nobody would deny that cattle raising is a notoriously inefficient way of using land, if the object is to produce as much food per acre as possible. We get far more nourishment from an acre of wheat than from an acre of pasture, and it is conceivable that if our situation becomes more desperate than it is, we may eventually have to become vegetarians. Since most of us want and need our meat, however, no one has seriously proposed that at this stage of our development we should depopulate our ranges and convert them into ploughed fields. Grazing lands are at least used to produce food, inefficient as the production may be. What we are concerned with is the potentially productive land that is not used at all.

These marginal lands, as they are sometimes called, are of many different kinds, and their utilization involves a wide variety of problems and techniques. Some of them are swamps, stagnant and boggy, and serving little purpose except as breeding grounds for mosquitoes. Others are slightly below sea level and are covered with a shallow layer of salt water. At the opposite extreme of elevation, some of these idle lands are at very high altitudes, where almost arctic conditions prevail. Many areas are unused because of industrial damage: strip mining, dumping of slag, open-pit storage of crude oil, and other practices have ruined many fine farms, and men have only recently begun to learn how to restore them to some sort of food production. Scientists have discovered, also very recently, that there are literally millions of acres of "completely worthless" land that are not worthless at all, but are only suffering from easily remedied deficiencies. Finally, we must include among the unploughed lands all those rich acres that are deliberately not planted because their owners are operating under the pressures of an economy of scarcity.

For centuries most of humanity took for granted the worthlessness of marginal land, and made no effort to use it. Even where population pressure in a given area made the use of every scrap of earth desirable, such places as swamps were regarded as inviolable. Early literatures abound in descriptions of desolate, soggy plains, haunted by nameless evils and putrid with the decay that thickens stagnant water, into which man might venture only at his peril. Later on, when some hardy souls began to live in the marshes, they made no effort to change the environment; they lived by hunting and fishing, accepting the dangers and discomforts of their lives so patiently that at length they came to regard them as amenities. When the English finally began to drain their Fens, and gave the inhabitants, among other things, a supply of safe drinking water, it is recorded that one old lady spat out of her mouth the first pure water she had ever tasted with the derisive comment: "Call ye that *water*? Faugh! It has neither taste nor smell."

At some places, of course, efforts were made very early to reclaim swampy land. Men worried for two thousand years, for example, over the problem of draining the Pontine Marshes in Italy, for they lay close to the city of Rome and were a perpetual nuisance to a highly civilized people. That splendid reclamation project has been carried out only in our own day. Similarly, the swamps of the fabled land of Colchis, on the eastern shores of the Black Sea, are only now being drained and converted into citrus orchards and fields where other tropical plants are grown.

Some say that the ancient civilization of Babylon was destroyed, not by conquering armies but by the hordes of mosquitoes that bred in the swamps of the Tigris-Euphrates Valley when the irrigation system broke down and the land was drowned by the sluggish waters. Be that as it may, there is no question that marshlands in many parts of the world today are a dangerous threat to our food supply, not only because they cover land that ought to be cultivated, but perhaps even more significantly because the malaria spread by mosquitoes lowers the vitality and hence the productiveness of farmers for miles around.

But there is no longer any mystery about swamp reclamation. The techniques of draining and channelling the stagnant waters, drying out the sodden land, and establishing a suitable agriculture are well known, and in many places they are being put into operation. The great Pripet Marshes in Byelo-Russia have recently been tackled, and are already yielding quantities of peat for fuel as well as furnishing thousands of acres of new land for cultivation. Yugoslavia has drawn up a plan for recovering over a million acres of swampy ground. One of the first projects attempted under this plan has been completed in the marshes of Jelas Polja in Croatia, where nearly 15,000 acres have been transformed into tillable land and part of it is *already under cultivation to rice. On the opposite side of* the planet, the Australians have undertaken to reclaim 30,000 acres from the Montague swamp on the island of Tasmania. The work of drainage and clearance, which is being carried out by the Land Settlement Division of Tasmania's State Water Service, is expected to require about eighteen years of work and the expenditure of nearly $8,500,000; in other words, the ultimate cost of what are expected to be extremely fertile farms will be about $280 per acre, a not unreasonable investment for permanently fine land.

Similar schemes, both large and small, are being undertaken in Italy, in China, in India, in Africa—indeed, right around the globe. A particularly interesting one in Africa, although still only in the planning stage, concerns the huge Bangweulu swamps in Northern Rhodesia. There are many swamps on the central African plateau, but the Bangweulu dwarfs them all. In its centre, three thousand square miles are under shallow water the year round, and during the rainy season the floods spread over an additional two thousand square miles, covering fertile grasslands and driving out thousands of people who ordinarily live there. The long-range plan now being considered provides for means of controlling these seasonal floods, and at the same time for reclaiming some of the perpetually submerged land and using the surplus water to enlarge the area of fertile grasslands around the edges.

The Bangweulu project is at present only a dream, although one very likely to materialize, but what has already been accomplished in many other marshes is clear proof that the centuries of superstitious acceptance of swamps as part of nature's unalterable malice are drawing to a close. Although we hear comparatively little about it, the peoples of the world are moving toward the production of an abundance of food. Whether it is to be achieved within the present century is the main question our generation must answer.

As for the land that can be reclaimed from the sea, the classic example, of course, is Holland, whose people have literally created a good part of the land they live on. Forty-five per cent of their territory is below the high-tide level of the North Sea, and every inch of it has been taken out of the clutches of the waves as generations of Dutch farmers and engineers have put their backs into the job of pushing against the tides. The reason for this gigantic seizure of ocean floor is not far to seek: if the United States were as densely populated as the Netherlands, we should have 1,250 million people living in the forty-eight states. For two thousand years the Dutch have been building their dykes farther and farther out into the sea, draining off the water, leaching out the salt, and establishing their marvellously efficient farms. Their masterpiece is the Zuider Zee Project, on which they are still working and which will give them an additional 550,000 acres when it is completed.

They suffered a cruel blow when the Germans, during World War II, opened dykes and let the sea rush in again, pouring salty floods over enormous areas of farm land. Yet the Dutch performed one of the miracles of reconstruction in Europe in speedily repairing the dykes and desalting the flooded land. All this has delayed the completion of the Zuider Zee Project, but has only demonstrated further the genius that will continue to create food-producing fields on what was formerly the floor of the North Sea.

In the meantime, the Dutch example is being followed in other places where a gently sloping bottom makes such reclamation feasible. Across the North Sea, the British are increasing the crop acreage of their island in the same way. In the spring of 1948 three farmers near Holbeach, on the Lincolnshire coast, decided to push the sea back from 1,500 acres of potentially rich land. The holdings of Alec Hay, Joe Ward, and George Thompson all stretched down to the great salt marsh of the Wash. For generations the rivers have brought down to the Wash rich deposits of silt, but the fertile land they have built was a dead loss to the farmers because the sea flooded in over it, the incoming tides bringing salt to poison the land and the outgoing ones sweeping away what the rivers had laid down. But the three farmers talked over their ideas with an engineering friend, Mr. E. G. Taverner, and the result was a plan for building their farm lands out into the sea.

What was required was a breakwater, a wall six and a half miles long, high enough and strong enough to resist the rush of the spring tides. The job of building such a wall kept a crew of seventy men busy for five months, and its completion was a triumph of perseverance. Since all the materials for the wall building had to be carried out from the solid land, the men spent most of their energy on haulage. At periods of slack tides they went lumbering out across the bog in discarded army "Weasels," caterpillared tanks that were supposed to be amphibious but that actually floundered and fell on their sides when they got into the water holes that dotted the swamp. It took four days for a "Weasel" to make the trip out to the wall and back, and before the work was finished the period of slack tides was over and the whole swamp was a mass of water. When this happened, the men took to flat-bottomed boats, loading them as heavily as they dared and gingerly working their way out to the wall, using their long-handled spades for oars. As the two ends of the wall came closer and closer together, the men had to struggle harder against the water, for each time the tide went out it had to be funnelled through a smaller opening, and this made such a roaring torrent that it threatened to destroy all they had built. But by bending the wall inward toward the land into a horseshoe curve, they were able to break the force of the tide and finally to shut out the ocean completely. Once the wall was built, it was planted with heavy grass; what remained to do was to drain the former swampland, and build it up by a few seasons of grazing into the condition where it could take crops.

The three British farmers, in a small and completely private undertaking, have shown what can be accomplished in building farms out into the sea. There are hundreds of other locations, both in the British Isles and elsewhere, where the same thing could be done.

The objection that is immediately raised by "practical" critics, of course, is that the cost of such reclamation is out of all proportion to its value. Quite simply, this is not true. The average cost of turning sea bottom into wonderfully productive farm land in Holland at the present time is about $200 an acre. Hay and Ward and Thompson spent £41,000 for their new 1,500 acres. That is no more than the sale price of equally good farm land anywhere. Furthermore, money spent in creating such land will continue to pay dividends as long as competent farmers use it; it is a permanent addition to human wealth and welfare. When you stop to consider that in order to pay the remaining balance we in the United States still owe for our part in the Second World War, we have in effect laid a levy of some $875 on every single cultivated acre in our huge country, you begin to wonder whether men in general could not agree on better ways to spend their money.

In the meantime, progress is being made in other directions. Just as the crops are moving northward into higher latitudes, so they are beginning to move upward into altitudes at which somewhat similar conditions exist. This vertical expansion is of course far less significant than the horizontal one, for the total area of cultivable land at altitudes higher than men are at present cultivating is quite limited, at least by comparison with the arctic regions. To individual nations and peoples, however, whose lowland farms are already overcrowded, high-altitude farming may offer a way of easing the strain.

Not a great deal has been done, so far, about these potential farms near the timber line, but there are indications that some nations are beginning to think seriously about the possibility of doing something. If they should, recent studies in the highlands of Bolivia may offer some suggestive hints.

More than half of Bolivia is low tropical country lying in the Amazon and Paraguay drainage systems. Although many Bolivians believe that the future agricultural wealth of their country will come from this region, it is at present very sparsely settled and little cultivated. Most of the population is concentrated in the valley-and-mountain section west of the lowlands, and on the high plateau still farther west. In this latter region, which is called the Altiplano, at an elevation of over 12,000 feet above sea level, about one-fourth of all Bolivians live, cultivating only some 88,000 acres out of the total land area of 40,000,000. Agriculture is a difficult and precarious business, and the yields of potatoes, barley, wheat, and the indigenous crop called quinua are so low that food has to be imported. Since development of the eastern lowlands seems very far in the future, the Bolivian government decided in 1949 to concentrate on improving the agricultural production of the Altiplano.

It was natural that the government should go for advice and help to one of the great agencies of the United Nations, the Food and Agriculture Organization. Established in October of 1945 by a large group of nations, it had been helping its members and others in any projects, separate or collective, that contributed to its constitutional objective of "raising levels of nutrition and standards of living . . .; securing improvements in the efficiency of production and distribution of food and agricultural products; bettering the condition of rural populations; and thus contributing toward an expanding world economy." Under the leadership of Sir John Boyd Orr in its early years, FAO had already attracted some of the best minds in the field from all over the world; it had become the principal clearing house for information on an international scale; and by procuring experts and sending them where experts were needed it had launched the work that is now known throughout the world as technical assistance.

Through the FAO, Dr. H. G. Dion, an agronomist from the University of Saskatchewan, went to Bolivia to make a preliminary study of farming in the western highlands. Drawing on the experience of Canadian farmers, and on his wide knowledge of conditions in northerly latitudes and high altitudes generally, Dr. Dion was able, in a ten-week study, to find many reasons for the low yields on the Altiplano and to point out a number of fairly simple measures by which those yields could be increased. Most of the soil, for example, is deficient in potash; since potatoes requir every large amounts of potash, the need for fertilization was obvious. Another cause of low yields is that for generations the Indian farmers have been in the habit of selling their largest potatoes and keeping the smallest ones for seed, with the result that they get fewer and fewer large tubers. And as with all other crops, Dr. Dion found that the potato varieties were seriously in need of breeding up, both for increased yield and for resistance to diseases and pests.

The principal problem with wheat seemed to be much the same as that encountered in the Arctic: the short growing season, which brings night frosts when the wheat is still in the blossoming stage. Dr. Dion suggested two possible remedies for this. In the first place, the Bolivians need to develop short-season wheats, which can mature in their climate. Since this will take time, they might try for the present using phosphatic fertilizers, for in other parts of the world, when there is a deficiency of phosphate in the soil, dressings of these fertilizers have speeded up the maturing of wheat as much as fourteen days. Dr. Dion's second suggestion was that they try the "dry-farming" methods in use in the northern plains area of the United States, in order to be able to plant their wheat considerably earlier than is customary. In regions of scanty rainfall, "dry-farming" is a system of taking a field out of production every other year, or one year in three. The land is cultivated to get rid of weeds, but it is not sown to crops. The result is that from 30 to 50 per cent of the rainfall of that year is held in the ground, and serves to nourish plants the following year.

In Peru, at several farms well above 12,000 feet in elevation, this method has been used successfully to produce earlier maturity: by ploughing in January and preventing weed growth through the rainy season, the farmers are able to plant their wheat around the first of September and bring their crops to maturity before the killing frosts.

Dr. Dion even had some interesting things to say about quinua, the traditional Indian cereal crop of the Altiplano. Quinua is a plant which has been given almost no attention by trained agriculturists, yet it has certain very definite virtues to recommend it, especially as a crop for high altitudes. It withstands frosts, and it is quite drought-resistant once it has become established. Most important, perhaps, quinua will grow on many soils where other crops will not, for it is very tolerant of salts. Perhaps these values may account for the experimental plantings of quinua on some high-altitude farms in Kenya, in Africa. At any rate, here is a plant which has provided the basic cereal for Indians in Bolivia for centuries, and it is one which the geneticists have not so far improved at all. It would seem that cross-breeding ought to do as much for quinua as it has done for other crops. A good, high-yielding hybrid, easier to harvest than the Bolivian varieties and with certain disagreeable qualities removed, might offer a valuable crop for high-altitude farms elsewhere.

At the end of his study Dr. Dion was able to show the Bolivians that the Altiplano could produce two or three times the amount of food it now yields. It would seem logical to suppose that similar results could be obtained in other countries at high elevations. And just as farming could be extended over many additional acres in the Bolivian Altiplano, so there are doubtless other cultivable areas on plateaus which have been assumed to be too high for agriculture. The geography of this planet is fairly well known, in general terms, but knowledge of its food-producing possibilities is by no means complete.

Quite well known, however, are the locations and extent *of all those once-rich farm lands which men themselves have ruthlessly destroyed through their sometimes ill-*advised efforts to build an industrial civilization. In the early years of prospecting and drilling in the great Mid-Continent oil fields, farmers simply abandoned their acreage when a gusher came in. In those extravagant days no preparation was made to catch the oil and pipe it into storage tanks until after the bit had actually penetrated the oil-bearing sand. Since there was usually considerable gas pressure under the oil, the well was allowed to "blow in," which meant that the oil and gas would suddenly come roaring up the hole, spouting out over the top of the derrick in a wild, greasy plume. It was a thrilling spectacle; people from miles around would rush out to stare at the fearsome sight, and newly enriched landowners would have photographs made of such magnificently conspicuous waste to be displayed on their desks or even on their personal stationery. Sometimes before the gas pressure was sufficiently exhausted to permit capping the well, the geyser would catch fire, and for weeks and even months a gigantic flare would stand high on the prairie, while men in asbestos suits tried again and again to get close enough to set off a charge of dynamite that would blow out the flame.

The pictorial and dramatic quality of the gushers was immense, but we paid for the show with many spoiled farms. Wherever the droplets of crude petroleum fell—and on an Oklahoma wind they were apt to be carried long distances—the soil was poisoned, with a corrosive poison that bit deeper and deeper as time went on. Even when the pressure was low, and the well could be capped and put on the pump immediately, the drillers would use open earth pits for the temporary storage of the oil. Seepage would then poison the soil in a wide area around the pit. Slush pits, into which mud, oil, and water are dumped when the wells are cleaned out, are still in use everywhere in the oil fields, and they perform a similar disservice to the topsoil.

The days of the gusher and of the open storage pit are about gone, but there are many badly poisoned farms that are still worthless for farming. Only gradually are agricultural scientists beginning to find plants that will survive on them, so that they can start putting them back into shape. The problem of rebuilding these diseased soils and restoring them to healthy productiveness is a long and difficult one, and we have barely started to solve it.

Strip mining is another industrial practice that spells death to farms. When a vein of coal or iron lies reasonably near the surface, it is customary, in order to avoid the digging of mines, to strip off the cover and make a vast open quarry. Giant bulldozers and earth movers push and scrape at the land, gouging out whole farms and piling them into mountains in which clay, rock, sand, gravel, and the few inches of precious topsoil are so intermixed they can never be separated.

Anyone who goes up into the Mesabi Range country in northern Minnesota can see in a little town there a high school with marble swimming pools and other evidences of fabulous wealth, built with the dribble of tax money the town was able to get from the companies that exploited one of the richest veins of iron in the country. But after the children have bathed in this Hollywoodian grandeur, they proceed to their tapestry-hung dining hall, and there they eat, by the grace of the School Lunch Fund, food that has been shipped in from farms many, many miles away. For all about the little town, as far as the children can see from their shining windows, lies desolation as lifeless as the craters and crags of the moon.

It is now known that such plenty in the midst of an appalling poverty of food-producing land is not necessary. When strip mining must be engaged in, it can be done without destroying for ever the farm lands under which the valuable minerals are found, and in Great Britain at the present time men are doing it. In that crowded island, with its highly industrialized economy and with stringent limitations on the amount of food it can afford to import, new supplies of coal and the conservation of every acre of cultivable land are equally essential. The British have therefore been forced to invent a new method of strip mining. It is slow, difficult, and expensive, but it is a masterpiece of human effort to have our cake and eat it, too.

Instead of sending the steam shovels in to dig indiscriminately, the first step in creating these new strip mines is an exceedingly careful removal of the topsoil only. As it is lifted off, this food source of the future is piled up by itself and protected from contamination. The deeper layers of subsoil and rock and clay, as they are removed later, are also kept apart, each stratum separate from the others, and an exact record is kept of the location of each in the original structure. When the coal vein is at last exposed, it is dug out as quickly as possible, and great precautions are taken to prevent any damage to the mountains of separate strata or to the surrounding countryside. There is of course inevitable destruction of buildings on the surface, and a few fine old examples of English architecture, some with historic associations of deep meaning to the British people, have had to be sacrificed. But the farm land has been saved.

When the coal is mined out, fill to the original thickness of the vein is brought in, and then, stratum by stratum, the covering is replaced. The final layer to come back to its former resting place is the topsoil, none the worse for having been an odd sort of mountain for a few years, rested and ready to go to work at its proper business of nurturing crops. The farmers, who have been temporarily housed and paid for the use of their land during the operation out of the profits from the coal, are resettled in newly built homes, and the daily round of ploughing and seeding and harvesting begins again.

It *is* expensive, but the British have found that the value of the coal and the value of rich farm land make it a thoroughly economic procedure. Better than most of us, they know these two values. They have also learned that when a farmer is taken off his land temporarily, with proper compensation, with the chance to work at his trade elsewhere while his farm is being mined, and with the assurance that he can return to his own fields in due time, he remains a farmer still; he does not become a derelict, as farmers uprooted by industrialization have often become in the past. This also is an economic asset of the first importance, but it can be realized only by nations that give the first priority in their national planning to what is after all the bedrock on which their whole social structure rests: namely, the production of food. Other nations would do well to profit from the British example, although it is unlikely that they will unless their mines are nationalized, for private companies would probably be unwilling to dig into their profits to the extent that is necessary for such conservation of the land.

Something can be done, however, to reclaim land that has already been seriously damaged by strip-mining practices in the past. In the state of Kansas, for example, where there are more than 27,000 acres of this man-created desolation, a fine rebuilding programme is under way. Back in the depression days the state discovered that it owned some three thousand acres of wasteland, because owners had simply stopped paying taxes on the worthless piles of debris left by the strip miners. Purely as a way of making work for idle boys, the state arranged for the Civilian Conservation Corps to plant black walnut seeds on this acreage, under the supervision of the national Forest Service. It is doubtful that anyone expected any results, beyond staving off some of the corrosive effects of unemployment from healthy young men, for such soil as was left was far below the minimum fertility walnuts were believed to require.

Strangely enough, however, the nuts sprouted and seedlings began to grow. While the plantings were still very young, the state suffered two severe droughts. But the little trees struggled on, and today on about two-thirds of the total area planted there is a fairly good stand of some three hundred to six hundred trees per acre. The trees have begun to bear, and where they are allowed to reseed naturally, the bare spots are beginning to fill in. The soil is still hopeless as a medium for growing field crops, but if it is let alone for a very long period, leaf mould and decaying matter will gradually create topsoil, the rich loam that always grows on the floor of a standing forest. Eventually the trees can be removed and the land put back to crops. In the meantime, the walnut plantations are providing cutting timber and a yearly harvest of edible nuts in addition to those left for the reseeding that will maintain and improve the stand.

Men have to pay for the wholesale destruction of farm land with work, and with years of patient waiting for the corroded soil to regain its health. But the price is small by comparison with the social and economic evils of allowing these blighted fields to lie waste and barren. At least some methods of preventing them in the future are now known, and some ways of erasing the scars left by earlier abuse. There are enormous tracts of "impossible" land in this world, both man-made and natural, on which human beings can some day grow their daily bread.

One such large tract of potentially productive land is the valley around Bari, near Bhopal in the centre of India. The floor of this valley is extremely rich and fertile; indeed, the fine black loam is said to be no less than three hundred feet deep. Until very recently, however, this unrivalled reservoir of good earth was useless to human farmers. It had been completely taken over by a tough, deep-rooted species of wild sugar-cane called kans grass. This obstinate plant, which is totally impervious to the traditional wooden plough, and which not even burning can eradicate, is the Indian farmer's most formidable enemy. It accounts for 80 per cent of the jungles that are gradually reducing the cultivable acreage in the subcontinent, and the Indians have been helpless to stop it. At present kans is in complete possession of 10,000,000 acres that could otherwise support crops. But the days of its rule seem to be numbered.

The reclamation of the valley near Bari has a long history.

Some twenty-five years before the present project was begun, an agronomist in the Indian government service, Daulat R. Sethi, discovered that kans could be destroyed if the roots were cut off a foot or more under the surface of the ground. It was virtually impossible to do this by hand, of course, and for a good many years the discovery went unused. After the Second World War, Mr. Sethi persuaded the Indian government to buy two hundred surplus tractors that had been used to build the Burma Road. With these, and some steel ploughs, he set to work. By dint of much labour, an area of 7,000 acres was eventually cleared. With this to offer as a sample of what could be done, the government of India was able to obtain a straight commercial loan from the International Bank for Reconstruction and Development to expand their reclamation programme. The $10,000,000 of this loan has been more than matched by an appropriation from the Indian government, under the terms of their vast Seven-Year Plan.

With some of this money, Mr. Sethi and his associates in an organization called the Central Tractor Corporation have bought not only a number of additional American tractors, but various other machines, including a root cutter which is unique among farming implements. It was originally designed and manufactured by a British firm for use in Tanganyika, but it proved to be useless in the rocky soil of Africa. The British redesigned it, giving it tough steel blades which reach down twenty inches beneath the surface of the earth and slice horizontally through the tangled kans roots. The roots go on down as much as four feet into the soil, heavily matted and intertwined, but as Mr. Sethi found out long ago, when the tops are cut off so far beneath the surface the deeper roots die.

This is one of the machines that was taken into the tiger-haunted kans around Bari early in 1951. Along with other modern equipment—steel ploughs driven by 150-horsepower tractors, push rakes, and stump-clearing machines—it began the task of converting 20,000 acres of the valley to wheatland. Already these machines are transforming the entire life of India. Farmers who are accustomed to struggling an entire day to plough with their bullock teams no more than a single acre, and this on land that has been cultivated for years, now see the root cutter opening up the jungle and the ploughs following along behind churning up the rich soil, the two machines covering more than an acre and a half every hour. In the twenty-inch top section the ploughs break up the mass of severed roots and expose them to the hot sun, so that they also die. Then the heavy mechanical rakes shake these dried roots out of the soil and clear them away for burning. The topsoil is ready to nourish crops.

The work near Bari is only one project in a series planned or already undertaken by the Indian government under its long-range programme. During 1950 and 1951, according to reports from India, around 400,000 acres were reclaimed in various parts of the country. The work was done mostly by Indians with the help of a small staff of mechanics and operators from Great Britain, the United States, and Australia, whose job was to teach the local personnel to handle and service the great machines. And those machines are by no means worn out: the average period of service of a hardworked tractor is seven years, so that they should be usable right up to the end of the Seven-Year Plan. During the first five months of 1951, 100,000 tons of food were produced from newly reclaimed land, so that the International Bank is assured of having its loan repaid with interest. For the Bank it has already been a good investment; for India it is one from which her farmers will be drawing dividends for generations.

In other parts of the world, other regions that nobody has ploughed are being brought under cultivation as science has discovered and conquered enemies more subtle than kans grass. In one of the most fascinating advances in recent agricultural research, Australian scientists have found a way to make fertile, productive fields out of thousands upon thousands of acres which were thought to be by nature for ever useless. In the south-east corner of the state of South Australia, there is a great barren area known as the Ninety-Mile Desert. Some sixty thousand square miles of this desert is a low, gently rolling plain called the Coonalpyn Downs, and in the middle of the downs a project has been started that will eventually make it possible for South Australia to pasture five million more sheep than it is raising at present. Headquarters of the new development are at the little town of Brecon, 150 miles from Adelaide and near the main railway connecting that city with Melbourne.

For a long time pioneers have been trying to settle the Ninety-Mile Desert, and for a long time they have been thwarted by some mysterious quality in the land that has baffled all attempts to track it down. For this "Desert" is not really a desert at all: the rainfall is good, sometimes as high as twenty inches a year, and even in time of drought there is an abundance of fine water at depths of from only 15 to 180 feet underground. The greyish-white, sandy soil looks fertile, and it passed all the tests that were known for fertility until very recent years. But the common forage crops would not grow on it, and neither would anything else except mesquite and scrub. So the settlers gave up, and moved some fifty miles down to the coastal flats where there was a good cover of native grass. But here again they were defeated: sheep put out to pasture quickly grew listless, stopped eating, and died. In some areas they survived, but instead of producing the normal crimped woolly covering of healthy sheep, their backs grew only a straight stiff hair called "steely wool" which no wool buyer would look at.

Since Australians have more land in their country than sheep to go on it, it was natural that the problem of what was wrong with the land in the Ninety-Mile Desert should be solved only after they had solved the more immediate question of what was wrong with the sheep on the coastal ranges. In 1936 a group of government scientists working for the Council for Scientific and Industrial Research found the cause of the "coast disease," that strange anemia that was killing off whole flocks. Like human anemia, it was caused by a nutritional deficiency. To be healthy, a sheep must assimilate 1/300,000 of an ounce of cobalt every day, an infinitesimal amount, to be sure, but much more than a human being needs. And all that was wrong with the coastal sheep was that their environment was not providing them with this minute trace of a rather common mineral. When exceedingly small amounts of cobalt were added to their salt licks, coast disease became a thing of the past.

Six years later came the discovery that put the saleable crimp back into the "steely wool." Again, the cause of the strange deformity was the lack of minute quantities of a common mineral. This time the missing element was not cobalt, but copper. When trace amounts of copper were added to their diet, the sheep promptly began to grow wool as crimped and springy as you please.

And so, eventually, the Australians began to wonder if it were possible that land, as well as sheep, could be made "ill" by the absence of a mere pinch of some mineral or other. The idea was not original with them; it had been slowly gaining attention since the early 1930's as copper and other minerals had been proved to be essential trace elements for the healthy growth of one crop or another. The soils of the Coonalpyn Downs, and of the Ninety-Mile Desert generally, were accordingly subjected to the most searching tests. And the most sensitive instruments could discover in those soils not even the trace of cobalt, copper, or zinc. Armed with this information, the scientists began a long series of experiments, adding, like master chefs, a pinch of this and a pinch of that to the sandy soils, and testing the results with a variety of crops. What they found as a result of all these tests has not only opened up vast tracts of barren land to the possibility of cultivation, but it has also added materially to our knowledge of some common crop plants, For example, it was found that oats need zinc but not copper, whereas lucerne demands copper, but can get along perfectly well without zinc; subterranean clover, on the other hand, requires trace amounts of both these minerals.

For a cost of approximately $1.13 an acre, the land of the Coonalpyn Downs can be given a dressing of zinc sulphate and copper sulphate which will ensure bumper crops for four years or more. The preparation of the land takes some time and money, for it must be cleared of native scrub and then allowed to lie fallow before it is ploughed and planted. It will be about six years before the first 20,000 acres will be opened for settlement, but a further 20,000 will be opened annually thereafter for a long period. The expense and work of preparing the land and settling it is being undertaken as a commercial investment by the Australian Mutual Provident Society, a private insurance company. Under the terms of a special lease granted by the state government, the holdings will eventually be divided into farms of 800 to 1,000 acres, owned by individual settlers. Eventually South Australia hopes to add the equivalent of an entire new province to its sheep land.

How many thousands of acres elsewhere in the world may be idle waste purely because they lack minute traces of some essential mineral is anybody's guess. But the success of the Australian experiments has unquestionably opened up a new approach toward the general problem of increasing our cultivable acreage. More is being learned constantly about the role of trace elements in agriculture generally, and with the establishment in 1948 of a world centre for the study of micronutrients at the McCollum-Pratt Institute of Johns Hopkins University, we may confidently expect this new branch of investigation to open still wider horizons.

Before we can make the most of all these new techniques for expanding the areas we cultivate, we shall have to *want* more land. In a world that is crying for food, one might think there was no question of our wanting it. Yet there is another kind of unused land on this planet that makes us wonder. Thousands of acres of perfectly good, fertile land are lying uncultivated by the deliberate choice of the men who ought to be farming them. How can such contradictions be?

Canadian farmers in 1940 harvested wheat from 28,700,000 acres; three years later they sowed only 16,800,000 acres. There in that one country nearly twelve million acres of usable wheatland were deliberately left fallow. It seems totally senseless, but the farmers had learned a bitter lesson: instead of producing to meet the world's need they had to produce in accordance with the capacity of their economy to distribute the product for consumption. There was simply not enough provision for storing and marketing the grain they could produce, and the people who needed it most did not have the necessary money to buy it. American farmers have been caught repeatedly on the horns of the same dilemma.

According to Sir John Russell, there has been no expansion of the wheat area in Africa and other potentially rich lands for the past twenty years, although there is land to spare. The reason is lack of facilities for storage and transport, and these facilities are so costly that they can be provided only when a permanent, stable market is assured.

Uneconomic use of land still persists even in thickly settled countries, although certain forms of it are mercifully disappearing. One of the largest agricultural estates in Great Britain, and one of the most profitable, is on land that twenty-five years ago was doing no one any good, and although it is expanding at the rate of 500 acres a year, it has many years of growth ahead. It is the Elveden Farm Estate of Lord Iveagh, which spreads over thousands of acres in Norfolk and Suffolk.

In the nineteenth century the historian Skertchly described the country on which this great farm is planted: " . . . so barren that one is often reminded of the deserts of Africa rather than of English scenery. Hardly a drop of surface water is to be found, and for miles there is neither ditch, pond, nor spring. Little cultivation is possible." At that time the owners had no desire to cultivate it; Elveden passed from one wealthy sportsman to another, including an Indian Maharajah who built on it a fantastic Oriental palace of carved marble, in which he entertained the wealthy and noble of many lands when they came to slaughter partridges and pheasants on a scale unmatched in shooting annals. Late in the century the first Earl of Iveagh acquired this Gargantuan shooting range and its marble guest house. He trebled the size of the mansion, bought up adjoining estates, and gave hunting parties that put the Maharajah's in the shade.

In 1927 the present Lord Iveagh inherited the 23,000 acres of brush and scrub and the outlandish buildings. Although he was fifty-three at the time, his inheritance did not suggest to him retirement into a social round of shooting. Instead, he moved into a cottage on the estate, put up twenty-five miles of rabbitproof fences, and began to plant deep-rooted nitrogen-building lucerne on the fenced land as fast as he could clear it. Today lucerne and farmyard manure have turned 9,000 acres of what was actually poor land into one of the best livestock, grain, and sugar-beet farms in England. Some three hundred people make their living on it, and the food it produces makes a big contribution to Britain's supplies. Although Lord Iveagh stopped all artificial game rearing long ago, every year on the unfenced parts of his land over 5,000 pheasants, 1,000 partridges, and 50,000 rabbits are shot, not for the dubious pleasure of killing but to be sent to the English markets for food. Lord Iveagh and his wife manage these enormous holdings themselves, with such close attention that it is said Lady Iveagh knows the name of every dairy cow in their vast herds. It is no wonder that the cultivated acreage at Elveden is steadily increasing.

In India, where the food problem is more urgent than in almost any country of the world, and where the stranger would imagine that every square inch would be planted to food crops, uncultivated land still equals in area almost 70 per cent of the cultivated. The cause is partly the poverty of the consuming public, and partly the holding of vast tracts by individuals like the Maharajah who once owned Elveden. Again, much of the cultivable land has been taken by jungle, and although a fine start has been made in eradicating kans, there are still many places where the jungle is on the march. But perhaps the most serious limitation on India's productiveness is not the land nobody ploughs but the fact that none of her land has ever been ploughed deeply enough.

Few regions in the world have such a deep layer of rich black topsoil as the alluvial plains of India. Under most of the 280,000,000 acres now cultivated, it extends downward for many feet, in places as much as three hundred. But the ancient wooden ploughs pulled by bullocks barely scratch the surface, turning only the top two inches. Through centuries of use without fertilization or rest, this thin layer has been exhausted. Agronomists have calculated that if only it were ploughed deeply, the average Indian acre could produce *three times* its present yield, and scattered experiments made by the Central Tractor Corporation have proved that these estimates are not exaggerated. Using admittedly inferior machines, they have obtained yields, simply by ploughing, of 1,200 pounds of wheat per acre from land that was giving only 450 pounds under the traditional methods of farming. Very significantly, they found that this increase paid, within one year, the cost of the tractor and plough.

Perhaps Earl Parker Hanson is right when he says in his *New Worlds Emerging*, "It is never a land that is overpopulated, in terms of inhabitants per square mile; it is always an economy, in terms of inhabitants per square meal." Certainly we can say that if the human population of this planet starves it need not be because of a shortage of land. We are not doomed by inevitable and irresistible forces of geography; there is world enough for all God's children. If we perish for lack of food, it will be solely because we refused to use resources that are adequate and completely within our own control.

VI. SALT-WATER FRONTIER

Food production can probably keep up with a population increasing at the rate of two new inhabitants every three seconds if the potentially cultivable land that is still available is developed and used. It is hardly likely that the addition of these new acres can make possible a genuine abundance, however, unless their cultivation is accompanied by higher yields everywhere. Conceivably, fifty years hence humanity might still be struggling for a bare existence, even though all the land that is usable were under crops.

But there is another source of human food besides the land, and it is one which ought to be investigated before turning to the question of crop yields. Land, after all, covers only about three-tenths of the surface of this planet, even if you include such permanently unusable land as the antarctic continent and other areas that are covered by thick layers of ice. The other seven-tenths is under salt water. And the oceans which cover it are still frontier territory, holding riches of which human beings are only dimly beginning to become aware.

It is true that this vast extent of water is not totally unfamiliar. From time immemorial man has looked at the sea and listened to its deep voice and wondered about the mysteries it holds. He has sailed across the surface of all the oceans; he has finally, as recently as 1948, mapped the last of the coast lines; from the most ancient times he has put down his nets and lines into the sea and drawn out a tiny fraction of its teeming life for food. But if one asks how far the race has utilized the resources of the oceans to contribute to human welfare, it becomes evident that up to the present we have only dabbled at the edge of the waves.

The description of the ocean as frontier territory is not an idle literary figure. Most of its great bulk is still totally unexplored and unknown. It is true that within the last century much has been learned, and that at present oceanographers have a fairly accurate, though sketchy, knowledge of marine conditions down to a depth of about six thousand feet. But the average depth of the sea is something like twelve thousand feet, and half of it is even deeper, going down to as much as thirty thousand. Of these abysses human beings know actually less than they know about galaxies and universes millions of light-years away from the earth. There have been a few deep-sea expeditions, and occasionally a stray inhabitant of some unexplored region wanders into the upper layer and gets caught by a surprised fisherman. When such creatures swim into our ken, they usually create quite a bit of excitement, because they often seem to be survivals of species which were thought to have disappeared long ago. The strange fish caught near the coast of South-East Africa early in this century belonged to a species that ichthyologists thought had been extinct for eighty million years. Knowledge of oceans in general is not quite eighty million years behind the times, but it is certainly primitive.

At the present time, however, some of the gaps in that knowledge are being filled in. More important, the human race is already in a position to make a much fuller use of the oceans than it has ever made in the past, not only because of new techniques for locating and exploiting richer sources of edible fish, but also because people are learning more ways of utilizing the whole fish instead of merely the more appetizing bits of its flesh. In addition to fish, other products of the sea are coming into wider use. Over and above all this, we are at present in the first fumbling stages of what may be a momentous change in the relation of man to the ocean, comparable with that change which made our remote ancestors food producers rather than food gatherers. And as if all this were not enough to establish the thesis that the oceans represent a new frontier, our technological ability is now sufficient for us to begin drawing on such other resources of the oceans as the water itself, the minerals it contains, and the power which, by one means or another, we can generate from it.

In the attempt to learn more about this vast body of water which covers seven-tenths of our planet, oceanographers are constantly at work, exploring, surveying, discovering. Just within the last few years they have filled in the maps of the ocean floor with several great mountain chains of whose existence they had previously been totally ignorant, and they have studied the outlines of chasms greater than any known on the land surface. Such mapping is fundamental, and the fact that it is barely begun serves to remind us that these are almost unknown areas. The explorers of ocean depths are performing a function strictly comparable with the work of those hardy adventurers who drew the first rough maps of such a continent as the one we inhabit. If anyone imagines that there may be no practical value in their discoveries, he might ask himself what he might have deduced about the iron deposits of Minnesota, for example, from consulting an early sixteenth-century map of North America.

One piece of pure speculation regarding a recently discovered phenomenon may serve to give an idea of possibilities. During the Second World War operators of echo-sounding instruments were bothered by a layer of some unknown material deep in the ocean which had the annoying habit of reflecting the impulses sent out by the instruments. Such a reflecting layer seems to be present in all oceans; it rises and descends at different times of day, according to the amount of light on the surface, so that it may occur at widely different depths; and in places there seem to be more than one such layer. Nobody knows precisely what this mysterious reflecting layer may be, but scientists who have investigated it know that it must be composed of masses of living organisms, because nothing inanimate would react so consistently to the amount of light in the water. Although the nature of these organisms is still unknown, so careful a scientist as Dr. Lionel Walford, who is chief of fishery biology in the U.S. Fish and Wildlife Service, has suggested that "this unknown thing, still unexploited, still unexplored

. . . may prove to be an extravagantly large food resource." In the present state of knowledge, such a suggestion is of course purely speculative. It is mentioned here simply to underline the fact that, as Grace Barstow Murphy has said, "The ocean is a large laboratory whose secrets we are bound to know," and that one of the primary secrets our scientists must attempt to unravel concerns the ability of man to extract from the sea more food.

They have actually made a great deal of progress in that direction, progress that is based not on guesswork but on observed fact. Since in the past human use of the food resources of the oceans has been confined almost exclusively to fishing, it is natural that a good part of this progress has been solely a matter of devising more efficient ways of finding, catching, and processing certain edible varieties.

Fish have been a staple source of food for so many centuries that one might think we would have discovered long ago all we need to know about them. Men have been catching fish ever since they have been men, and from the earliest times they have made hooks, nets, and traps to catch them with. Even Stone Age men patiently sharpened slivers of bone or rock that would catch in the fish's throat and fasten him to a line. The fish was so important in some primitive economies that it was deified, and many early religions centre about the worship of a fish god or goddess. In Egypt today, Moslem, Jewish, and Christian children still wear fish-shaped amulets around their necks when they go swimming. In the Christian religion the fish has always been a venerated symbol, and you will find on the steeple of many a church a weather vane on which a gilded fish still informs the parishioners of the way the wind is blowing.

Yet despite this long acquaintance, ignorance regarding fish and their ways is still far greater in extent than knowledge. Ichthyology and all the related sciences are still being fruitfully studied, and important discoveries are made every year. Of immediate bearing on the problem of increasing our food supplies are the frequent, and indeed constant, discoveries of new fishing grounds. One or two simple examples will suffice to illustrate.

The great codfish industry of Norway depends primarily on the catch from waters off the northern coast of that country. The Norwegians are a systematic people, and over a long period their statisticians have kept track of the yield from those fishing banks. Looking over the record, they have noticed that about every ten years the supply falls off, and there is a period of several years during which the fishermen have rather hard times; on the basis of past experience they can predict the onset of this periodic decline.

The last time that a slump was seen to be imminent, the Norwegians decided to look for new fishing grounds that could be used to tide them over the time of reduced yields from their own. They found one on the west side of Greenland, in waters where virtually no cod fishing had been done. Furthermore, it is not just another codfish bank; the fish are abundant, and they are an unusually vigorous and long-lived strain, which means that the yield will be heavy for many years to come.

Practical fishermen are constantly making this kind of discovery. At about the same time the new codfish bank was located, some other Norwegians found a new and very rich hunting ground, near Ellesmere Island, for the Greenland shark. From the first exploratory voyage they returned with eight hundred barrels of medicinal liver oil. And so it goes, all the time and all over the world. By the casual, trial-and-error methods of practical fishermen, it is constantly being demonstrated that the oceans are by no means fished out.

In their work of locating new fishing grounds fishermen are aided, of course, by the oceanographers, the ichthyologists, and a host of other scientists, who provide them with needed information and with more efficient instruments. The Greek fishing industry offers a pleasant example. Before the Second World War, Greek fishermen had gone about their work entirely on the ancient trial-and-error basis. But among the first shiploads of UNRRA supplies to be delivered at Piraeus early in 1946 were two echo sounders. A year later twelve UNRRA fishing vessels arrived, equipped with depth recorders and carrying American crews who were eager to show the Greeks how they could measure the depths of their traditional fishing grounds and possibly discover new ones. Many of their pupils were sceptical, but a certain skipper named Konstantinos Kritikos was fascinated by the possibilities that seemed to be opening. He promptly equipped his trawler "Naftilos" with all the modern gear he could get, and one day he slipped away from his cronies who were working the accustomed fishing grounds and set out to explore. The next time his friends saw him, he was selling a truckload of hake, prawns, and shrimps in the Piraeus market. Immediately a chase began. For ten days the "Naftilos" eluded the other fishing boats, disappearing into strange waters and returning from each journey laden with fish. Finally she was tracked down, and the rest of the fleet began to share in immense hauls from deep waters they had never fished before. Konstantinos Kritikos had discovered the richest of all present-day Greek fishing grounds.

Even the "pure research" scientists, who study one angle or another of the total problem for the sheer pleasure of satisfying their human curiosity, are constantly adding proof to the theory that the oceans contain a far greater wealth of recoverable human food, particularly of rich and essential proteins, than we have ever used. A case in point is the expedition that started out from Cambridge University in 1924 with the purely disinterested purpose of seeing what forms of marine life might be able to survive in such a narrow, traffic-fouled waterway as the Suez Canal. Where the canal spreads out into the Bitter Lakes, about midway between the Red Sea and Port Said on the Mediterranean, the expedition found colonies of a large and delicious prawn that is of considerable commercial value. Previously this prawn had been caught only in the Red Sea itself, where it was not worth much to humanity because there are no large populations nearby to consume it.

As early as 1898 another edible shellfish formerly found only in the Red Sea, a swimming crab, had been noticed at Port Said. In 1924 it looked as if the prawn as well might be migrating through the artificial strait. This supposition has now been confirmed; both the prawn and crab have reached the Mediterranean and their colonies have multiplied and spread to areas where they are easily accessible to fishermen who supply very large markets. A few of the shellfish have gone westward as far as Alexandria and Mersah Matruh, but since the current at Port Said sets strongly to the east, a much larger number have moved toward Palestine. Another British research man recently found them well established off the coast of the new state of Israel, where they may have some real economic importance; for although the Israeli are forbidden by their religion to eat these shellfish, there is no prohibition against their selling them to the rest of us.

This constant discovery of new and richer resources—and these are only a few examples out of hundreds—tends to encourage the frontier psychology of wasteful exploitation which has characterized most of our use of the sea and its products in the past. Gradually, however, under the pressure of apparent or actual shortages in the supply of certain species, this attitude is being replaced by some definite attempts toward conservation. Of recent years, most international treaties concerned with fishing rights (or hunting rights, where the prey is one or another of the marine animals) have included provisions designed to protect and increase the source of supply. In many instances, particularly in the treaties concerning whaling, there is room for a great deal of improvement.

Whaling was for so long a complete free-for-all that there has been a very real danger of the total extinction of this extremely valuable animal. For six centuries the Basques in France and Spain hunted whales in the Bay of Biscay so recklessly that today the species they exploited is extinct, and there are no large whales of any kind in the whole middle Atlantic. In fact, the only herds worth hunting now are in the Antarctic, and whalers are worried because those herds are getting smaller.

And yet the whale is much more important to our well-being than most of us would think. It is true that we no longer have much need for what is erroneously called "whalebone"; this is the baleen, not bone at all but a huge set of spring bristles, six to ten feet long, that grow in the jaws of the toothless varieties of whales. Medieval knights bought quantities of it from the Basques because by fastening a thin strip on their helmets they could make the plumes nod and sway in a highly effective manner. Victorian ladies also coveted baleen for their corset stays, but today the small amount on the market is used principally for making industrial brushes. But the baleen whale is still vigorously hunted, because it also produces an edible oil, and in quantities that make it important in world economy. Of all the edible fats consumed by the entire human population, 10 per cent comes from baleen whales.

The oil of the toothed varieties, the sperm whales, is not edible, but it is valuable as a source of fine lubricants, cosmetics, illuminants, and many other products. From the livers of both baleen and sperm whales we derive valuable vitamins, and recently two Danish doctors, Hagedorn and Sterling, have learned how to extract from a single whale pancreas more insulin than is obtainable from five hundred hogs. With diabetes on the increase, the salvaging of these formerly wasted glands is in itself a major achievement. More recently still, Norwegian factory ships have begun extracting ACTH, the anti-arthritis hormone.

Whaling crews have always eaten whale beef, and now that quick-freezing has made possible its long-distance transportation, it is becoming a frequent article of diet in some meat-hungry parts of Europe. Where the old-time captains threw away mountainous carcasses, once they had taken the blubber, oil, and baleen which they could sell, modern science has enabled us to waste very little of the entire animal body. The bones are ground to make a high-grade fertilizer; much of the offal is processed into a nutritious meal that is greatly fancied by silver foxes; and scientists are at work trying to dehydrate the blood, so that it may also be used as animal feed and fertilizer.

This serious and persistent attempt to discover and use all the possible by-products of the whale is of course characteristic of our industrial society in its present stage, and it is paralleled by similar activity in the major fishing industries. The pressure toward making more economic use of the total catch has already led to such interesting new industries as the plant in Scotland which makes oleo-margarine from excess herring: that part of the annual catch which exceeds the market demand and was formerly thrown away as "surplus." In the United States, the Office of Technical Services is interested in the possibilities of extracting vitamin-A oil from salmon waste, and of using salmon eggs for proteins and industrial fats. In Norway, codfish and herring waste are converted into everything from plastics to cosmetics, and recently a process has been discovered for making albumen, or "egg white," from the same source. From ten or twelve pounds of fish waste comes a pound of dried egg white, the equivalent of the daily production from some 165 hens.

Significant as such developments are, they are merely refinements in an economy that is still on the primitive level of food gathering. Man is still trusting entirely to the caprices of nature to keep up the supply, no matter how earnestly he may try to find new natural sources and to use every particle of the catch. But there is much evidence to indicate that he is at long last beginning to become a *producer* of food from the ocean. The beginnings of this revolutionary change of relationship are evident in such simple procedures as the "farming" of seaweed.

From time immemorial coastal dwellers have gathered seaweed, either picking it up from beaches where it had been washed by the tides, or going out in boats to cut it with long, hook-shaped knives and haul it to shore. The Japanese have long used it for making everything from soap to soup, and in many parts of the world a great variety of local dishes are made from the different kinds of seaweed found in the coastal waters. Until the early nineteenth century seaweed was almost the only source of commercial iodine, as well as an important source of potash. It is widely used as a fertilizer, and from the cellulose which it supplies in quantity manufacturers make paper, synthetic leather, high explosives, stockings, linoleum, and a variety of other things, ranging from jellies and condiments to upholstery stuffing.

Until quite recently all the industries that have used any of this great family of plants to supply their raw materials have depended on the casual harvest of wild growth. Now, however, the picture is changing. The Irish learned quite a while ago how to place rows of large stones in fairly shallow water to trap the weed and encourage its growth. The Japanese now cultivate rather extensively the type known as red laver, and experiments in growing this and other varieties are under way in Scotland. One of the largest of present-day seaweed "farms" is off the coast of California, where 3,000 acres of tended beds yield around one hundred thousand tons of seaweed every year.

It is evident that seaweed farming is in its infancy. Only a few types are at present used, and there are not many farms for systematically cultivating even these. Yet the algae are an enormous family, ranging from microscopic one-celled plants to great treelike forms with trunks two or three feet thick. The possibilities of extracting food and other commercially useful products from most of the varieties have never yet been investigated, so that no one knows what riches these underwater forests may hold. What is certain is that as new values are discovered it need not be left to nature and chance to determine how much of them men can have.

Men have actually undertaken the deliberate husbandry of some of the animal life that flourishes in sea water. It was natural that sponges should be among the first marine animals to be raised, since unlike most animals they are stationary. Large beds have been "planted" in the Bahamas, and it is possible that artificial cultivation may become general. Considerable work has been done also with oysters. In natural conditions the infant mortality rate of these shellfish is staggering; although a female oyster lays about five hundred million eggs during her life, only some five hundred of her offspring reach maturity. The work of the oyster "farmers" so far has been directed toward giving baby oysters something better than this one-in-a-million chance, by keeping away the parasites and animals that prey on them. The method has been to put the spat in tanks containing a supply of food, and transfer the young oysters to marine beds when they are large enough to fend for themselves. Of course we cannot save all the millions of larvae; if this impossible ideal should ever be reached, fifty female oysters would supply all we are at present consuming. But since the human race could eat a great many more oysters than it does, to say nothing of using the very pure lime in their shells for soil improvement and for many industrial purposes, it seems likely that oyster farming will be continued and extended.

From such experiments as these scientists have gone on to a far more significant task: they have started the mass production of edible fish in the sea. The raising of fresh-water fish in hatcheries and carefully tended ponds has of course long been practised. Carp ponds are very ancient, and their modern counterparts, in which a variety of fish are grown, are becoming more and more common. This is not surprising when one considers that from a well-managed pond a farmer can expect up to 300 pounds of fish per acre, whereas he can produce at most 150 pounds of beef on an acre of land. But in a fascinating experiment along the west coast of Scotland, a lean, bespectacled scientist named Fabius Gross has recently demonstrated that man can control

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and greatly increase the production of salt-water fish, with the result that it is now possible to get a dependable and very much larger supply of certain edible varieties.

Dr. Gross and his staff are none of them fishermen: he is a science lecturer at the University of Edinburgh, and his associates are men from the Marine Biological Station at Millport and technicians from the laboratories of the Imperial Chemical Industries. But they have done something far more important than catching fish. They have produced, in the natural habitat, salt-water fish of marketable size in three years instead of the normal six. This simply means that if their practices were extended to a large field, the present supply could be doubled.

The first problem was to find a body of salt water in which the environment could be controlled. All up and down the west coast of Scotland the sea bites in deeply in a series of lochs or firths, like the fjords of Norway. One of these deep and nearly landlocked arms of the sea is Loch Sween. At its northern end it is connected by a narrow artificial channel with a small body of water known as Loch Craiglin. For their first trials Dr. Gross and his associates chose Loch Craiglin, for since it could be isolated when necessary to keep the little fish in and their predators out, it offered the possibility of a controlled experiment.

They soon found that the only thing necessary to produce large fish quickly was to give them enough to eat. The feeding is not done directly, however. Fish live on smaller fish, and the smaller fish in the ocean feed on plankton, the mass of microscopic animal and plant life with which sea water swarms. Since the ultimate source of all animal life in the sea is the plants, Dr. Gross reasoned that if they could increase the quantity of these tiny plants they should eventually make the water support more fish. In order to grow rapidly these one-celled plants need potassium, which is already sufficiently abundant in sea water. But they also need nitrogen and phosphorus, and the reason there are not more fish in the sea is that these two minerals are deficient.

What the professor and the skilled laboratory technicians did, therefore, was simply to go out in a motorboat every eight weeks and shovel sodium nitrate and superphosphate into the water of Loch Craiglin, which they had previously stocked with plaice and flounder minnows.

After five years of this work the results were so gratifying that the experiment was extended to less protected waters. In Kyle Scotnish, a 200-acre strait in Loch Sween that has direct access to the open sea, the experiments with fertilization are going ahead. There is every likelihood that tides and currents will wash away some of the fertilizer, and that some predators may be attracted to the feeding grounds, but it is not likely that the edible fish themselves will stray very far away from a place where food is abundant. If the attempt in Kyle Scotnish is even partially successful, it will mean that the project is economically sound, for the fertilizers are not expensive and the labour involved is negligible. Dr Gross is looking forward already to the next and final step: the fertilization of fishing banks right in the ocean. What has already been proved is that the cultivation of marine fish is not a fantastic dream; on the contrary, under certain conditions it is a highly profitable undertaking. There seems every reason to believe that in the future ocean fish farms may become no more outlandish than livestock ranches. If they do, the food supplies of the world ought to be considerably increased.

In the meantime an even more revolutionary kind of water farming appears to be in the offing. It is revolutionary not merely because it involves the use of a new and virtually inexhaustible source of food, but because it enables man to produce *at will* the particular *kind* of foodstuff he most needs.

One of the least prepossessing members of the great algae family is a tiny one-celled plant called *Chlorella pyrenoidosa.* Under the microscope it appears as an insignificant spherical blob of living matter; populous colonies make up the bright green slime you see hanging from the lips of a cow that has drunk from a stagnant pond. Of all the plants in the world which might be considered a possible source of edible food in large quantities, Chlorella would seem to be among the least promising. Yet because scientists have recently obtained a measure of control over its food-producing functions, this rather nauseating slime may offer one of the important keys to a world of abundance.

Several years ago, H. A. Spoehr and Harold W. Milner, with their colleagues at the Carnegie Institution's Division of Plant Biology, undertook to establish whether it were possible to change the chemical composition of a plant by growing it under different environmental conditions. They selected Chlorella for their experiments because it is a very simple plant, fast-growing and easy to handle, and because chemists and biologists had long used it to study the elaborate and still mysterious process of photosynthesis. This is the process by which plants, using sunlight for the necessary energy, convert inorganic elements like carbon and oyxgen into the foodstuffs (proteins, carbohydrates, and fats) upon which all animal and human life depends.

Chlorella happens to be a very efficient little food factory, Its entire body is a compact mass of food with only the thinnest possible skin to hold it together. But it has never seemed worth while to try to process this food into a form that would be palatable to animals and human beings, because under natural conditions the food manufactured by Chlorella is largely carbohydrates, and we have ample supplies of carbohydrates from more easily available sources. The really scarce food substances are proteins and fats, and Chlorella in its natural state produces only a small percentage of protein and a still smaller percentage of fat. The problem Milner and Spoehr set for themselves, then, was to see if they could induce the little plant to change the proportions of these three basic foodstuffs.

In their laboratories at Stanford, California, that is exactly what they have succeeded in doing. They found, in the first place, that if Chlorella had more of the essential inorganic elements to work with than nature normally provides, it could produce more food. So they tried adding extra nitrogen and other minerals to the water where the plant was growing, and bubbling through the water a great deal more carbon dioxide than the plant could draw from the air. Then they gave it plenty of light and let it grow for a long time. With all these extra inducements, Chlorella flourished like the proverbial green bay tree. But although the scientists now knew how to get a very large amount of growth, the proportion of carbohydrates, proteins, and fats was still unchanged.

Then began a long series of manipulations of the various factors that had produced the richer growth. Of these, the amount of fixed nitrogen in the water and the time of exposure to light proved to be the two factors that could produce changes in the chemical composition of the final product. Large amounts of carbon dioxide, nitrogen, and light had produced merely a larger quantity of ordinary Chlorella when the plants were allowed to grow a long time. But the scientists found that a *shorter* period of growth caused a most important change: richly fed Chlorella, harvested in the early stages of its growth, contained much more protein than it would if allowed to grow longer. Working along the lines suggested by this fact, they have been able to harvest a plant in which 58 per cent of the dry weight is edible protein.

Even more startling are the changes that have been achieved in fat content. Here the determining factor seems to be the nitrogen. If, instead of supplying ample quantities, the amount of nitrogen is cut down to a known minimum, while at the same time the plants are given plenty of carbon dioxide, plenty of light, and a long time of growth, the proportion of fat in the final product goes up enormously. The result has been a Chlorella in which pure fats accounted for as much as 86 per cent of the dry weight.

Now what does all this mean in terms of our ability, practically, to produce the particular food substances which we need? There are several implications. Scientifically, the significant thing is that scientists have been able to force a particular plant to produce the kind of food substances we need instead of the kind we don't. Whether they may eventually be able to extend this sort of control to some of the larger and more complex plants so that men could, in some "science-fiction" world of the future, pick pork chops from trees, is a matter of speculation which at present we do not need to pursue. But in terms of practical food-producing possibilities, this series of experiments is of the utmost importance.

There is first the question of the quality of fats and proteins that Chlorella synthesizes. Both have been analyzed and tested, and Milner has reported that both are good. The fat seems to be about the same as that produced by other plants, and there is no reason to suppose it would not make as good food as, say, soya-bean oil. The protein contains all the essential amino acids in unusually large quantities, and is one of the richest plant sources yet found for several important vitamins. Here, then, is certainly usable food, if it can be produced in quantity.

At the present moment the large-scale farming of Chlorella is under very serious study, and it has progressed to the point where competent engineers are convinced it presents no problem that cannot be solved. What are planned, roughly, are farm-factories in which the plant can be grown in a continuous system of transparent pipes or tanks, harvested, and processed into edible materials. The results that are expected are breath-taking. Since the water could cover nearly all the surface of the given area, which would enable the plants to use the maximum amount of sunlight, and since continuous culture of these fast-growing plants would permit, in the proper climate, virtually year-round production, the potential yield completely dwarfs anything we can hope to obtain from ordinary field crops. Very conservative estimates indicate that from an acre given over to the cultivation of Chlorella for high-protein yield, we could confidently expect to harvest twenty tons of dry protein and two tons of fat annually. If the Chlorella were cultivated in such a way as to produce a high fat content, we could get as much as six tons of fat from a single acre every year. When you consider that the best yield of soya-beans is about 225 pounds of oil per acre, and that of peanuts is some 350 pounds, you begin to grasp the revolutionary possibilities that are opening before us.

It is too early yet to say whether the cost of growing Chlorella on a large scale can be brought low enough to make it commercially successful in a competitive economy. Certainly the major nutrients—water, carbon dioxide, and fixed nitrogen—are plentiful and not expensive, and sunlight is free. Some serious investigations have been made, notably by R. L. Meier of the University of Chicago, toward the possible use of Chlorella for industrial purposes, chiefly by fermenting the algae to alcohol. But no pilot plant for food production has yet been built, and the initial cost of building a farm-factory has not been determined. More importantly, almost nothing has been done toward investigating the methods and cost of processing the raw fats and proteins into palatable food, and this cannot be done until pilot plants are producing sufficiently large quantities of dried Chlorella for extensive experiments. But what is clearly established is that the production of undreamed-of quantities of needed fats and proteins is scientifically and technically possible. In a world threatened by hunger this fact is so important that further study of the economic problems seems obligatory.

The possibilities latent in this remarkable series of experiments are by no means limited to Chlorella. It, after all, is only one of the numerous single-celled algae, and it happens to be a fresh-water variety. There are many, many others, both fresh-water and marine, and it may well be that some of them contain richer possibilities than Chlorella. No one knows, because no one has studied them. But if, by controlling the various factors that aid in growth, biologists can predetermine the kind and the quantity of foodstuff that Chlorella will produce, it seems reasonable to expect that they can do the same thing with whatever other varieties may promise a comparable reward.

Of particular interest are the salt-water algae. Since some ninety per cent of all photosynthesis takes place in the ocean, there being far more plants in the sea than on land, there is an infinitely larger potential in marine plants than in the fresh-water varieties. Dr. Gross's Scottish experiments in ocean fish farming have already demonstrated that fertilization of protected coastal waters results in tremendous increases in the amount of phytoplankton, that is, of microscopic plant life generally. Now that Milner and Spoehr have devised a technique that enables them to control the quality as well, there would seem to be literally no limit to the possibilities. Cultivation of algae in landlocked bodies of salt water would doubtless be less efficient than similar cultivation in sterile pipes of fresh water on land, because the growers could not exercise as complete control over the environment of the plants. But since it would also be far cheaper than building and operating a water farm on land, it might very well be a more economic procedure.

The cultivation of Chlorella for specified yields of protein or fat is at present hardly out of the laboratory stage. Yet so indisputable are the facts that have already been established and so significant, that commercial companies are already at work on projects designed to make a large-scale use of the scientific discoveries. It has also been suggested that the United States government undertake large-scale production for the purpose, not of competing with domestic production of the conventional foods, but of enabling such countries as Japan to overcome their shortages. Pending such generosity, the governments of several heavily populated countries, among them Ceylon, are seriously studying the possibilities of establishing Chlorella culture themselves, and there have been reports of similar plans in Israel and Japan.

All this activity, in what amounts to a totally new area of human endeavour, serves to underline again the fact that the waters of the world, and specifically the oceans, are still almost completely undeveloped frontier territory. But it also serves to remind us that mankind is now ready, with the necessary technical and scientific equipment, to begin the development of this vast frontier region on an unprecedented scale. It seems not outrageous to suggest that the oceans may someday produce a greater proportion of the food consumed by human beings than is grown on the land.

Other Resources in the Ocean

APART FROM food, the most obvious resource in the ocean is the water itself, in quantities which, as everybody knows, are to all practical purposes inexhaustible. No one ever bothered about it until hydrologists began to notice, some while ago, that the supply of fresh water is in many places becoming dangerously low. Many cities in the United States have in the past few years discovered to their horror that they face dangerous shortages, or even total loss, of the simple fluid without which civilization, or indeed human life in any form, cannot exist. In many other countries, too, the water table is falling at an alarming rate, because of the heavy demands of our steadily increasing population and our expanding industrialization.

Since the problem is to find more usable fresh water, one may wonder what this has to do with the ocean. The answer is very simple: it is possible to freshen salt water. All the desalting methods that are at present used on a small scale in the desert countries are being studied with an eye to the large-scale conversion of sea water into the pure liquid we use for drinking, bathing, irrigation, and a thousand other purposes. In addition to the ion-exchange method, which seems among the most promising, there are a variety of others, ranging from ordinary distillation, which is too expensive, through the vapour-compression distillation process, by which freshened water would cost about a dollar per thousand gallons, to refrigeration, which nature practises extensively in the polar regions but which man has not yet learned how to do economically. It seems possible that within the foreseeable future giant installations may be actually engaged in supplying coastal cities like New York and Philadelphia with their daily quota of millions of gallons of usable water drawn from the ocean. If they are not, the cities may not be inhabited.

It is possible, also, that in the future mankind will make increasing use of the minerals with which ocean is far more plentifully supplied than land. There is little likelihood that we shall ever extract much gold from the sea, although more of it exists in sea water than has been mined on land since the beginning of history, because by the only methods known at present it costs five times as much to get it out as it is worth. But gold, after all, is a nearly useless material, and for its few valuable functions there are plentiful substitutes, so that its total disappearance from human use would be no great loss.

Magnesium is an entirely different matter. Wherever we need a metal that combines strength with light weight, notably in aeroplane parts but also in a variety of other products, we rely more and more on the magnesium alloys. Now it happens that in every twelve cubic feet of sea water there is nearly a pound of magnesium in solution. Furthermore, economic processes of extraction have been known and used since 1939, and plants are now extracting the metal in quantity both in Great Britain, where the technique was originated, and in the United States.

There are also tempting quantities of other valuable minerals which men may some day find it necessary to recover. Bromine is already being extracted in the United States, and the daily production of one large plant, which handles some thirty million gallons of water a day, is around fifteen thousand pounds. It is conceivable that eventually men may have to "mine" the oceans for such minerals as aluminium. Although it exists in much smaller quantities—only 8,000 tons in a cubic mile, as compared with 283,000 tons of bromine and about 6,000,000 tons of magnesium

—it might nevertheless be worth extracting when more of the reserves on land have been used up.

Of course the concentration of these and other minerals is higher in some of the landlocked bodies of salt water. It has been estimated, for example, that the Dead Sea contains nearly six thousand million tons of magnesium, and before the partition of Palestine Jewish industries were taking quantities of other valuable materials from that source. America has long used the waters of its Great Salt Lake, and there are other similar inland seas which may be developed as time goes on. Yet it can safely be said that there is far more wealth in the oceans than men have yet thought of recovering.

It may be possible eventually to combine in some way the processes of mineral extraction with one of the desalting and purification systems, so that we could make a double use of the water. Such an arrangement would substantially reduce the costs of both operations. And there is, finally, another resource in our oceans that might very well be used in combination with these other two. Any large industrial plant requires power, and the waters of the sea are capable of providing sizeable amounts.

Two possible ways of developing electric power from the ocean have so far been suggested. The first and most obvious uses the energy generated by the tides which at certain points on many coast lines sweep in and out with great force. The principle involved is the same as that employed in any hydro-electric system, except that instead of using the energy of water falling vertically, the turbines are harnessing water as it rushes along horizontally. The principal drawback has been that twice a day, when the tide is turning, there is a period of virtual immobility during which the production of power stops. A continuous electric current has been achieved, however, by either of two methods: either the tidal power installation is supplemented by a small plant which generates electricity from one of the common fuels during the time when the tide is not running;

or a part of the tidal water is led into reservoirs from which it can be released in temporary waterfalls. Tidal power installations are in operation in various parts of the world, one of the most successful being on the coast of France near Mont St. Michel, and others are being planned.

The potentially recoverable energy in the tides, however, is small by comparison with that which may be obtained by another, and fascinating, procedure. In 1926 two French physicists, Georges Claude and Paul Boucherot, presented to the Academy of Sciences an astonishingly simple experiment which has been tantalizing a number of French minds ever since. They set up on a table a small apparatus consisting of two glass balls connected by a glass tube. In the first ball water warmed to only 86° F. was boiling in a near-vacuum. The steam passed through the glass tube into the other ball, where, also under very low pressure, it condensed back into water at a temperature of around 45° F. What astonished the academicians was that there was a miniature turbine inside the connecting glass tube, and as the steam passed through it set the turbine spinning, with the result that an electric light bulb attached to the apparatus began to glow.

But the most surprising thing was the use Claude and Boucherot proposed to make of the principle they were demonstrating. The proposal sounded fantastic, but the grave members of the Academy were inclined to listen to it respectfully because of the eminence of Georges Claude. He had long been known as a technician of the first order, whose various discoveries had had far-reaching practical effects. For example, as early as 1897 he had given the acetylene industry its greatest boost by rendering acetylene non-explosive through dissolving it in acetone. In 1902 he had succeeded in liquefying air, and in obtaining nitrogen and oxygen separately from a liquid mass. We even owe to Georges Claude our neon signs, although when he first made the luminous tubes in 1910 he used them not for advertising but for various purposes useful to the young science of radiotelegraphy.

Because of this background, Claude was able to find an audience who would listen when he began to talk about his little apparatus and what it might suggest in connection with the ocean. Is it possible, he asked, by making use of this principle, to generate electricity from tropical oceans, where there is a surface temperature of 75° or 80° F. and a temperature at depth very near to the freezing point? Would it be possible to draw the warm surface water into a "boiler" where, under a vacuum, it would turn into steam? Could the cold water from a depth of some six thousand feet be brought up and made to cool a condenser so that the temperature could then be brought down to as low as, say, 45°? And could the energy released by these exchanges of heat be harnessed by turbines and made to turn high-kilowatt generators?

The attempt to answer these questions has taken more than twenty years, primarily, it seems, because the experimenters made a basic mistake in their engineering plans. Since the first effort to set up a floating power station ended in disaster off the coast of Cuba in 1930, when the poor little boat Claude and Boucherot were using sank under the weight of all the necessary machinery, repeated attempts have been made to design a ship large enough and strong enough to carry the proposed installation. Such is the mind of man, once he gets a notion fixed in his head, that these plans and designs have continually expanded to larger and larger proportions. As early as 1927 Boucherot thought they needed a ship of 500,000 tons; by 1944 the dream had culminated in the fantastic proposal of a ship made of concrete and displacing two million tons.

Long before this point was reached, Claude had withdrawn from the picture. After the failures of 1930, he turned away from science to politics, of the rightist variety. But in the following years other scientists continued to toy with the idea of building a floating power station to tap the energies in the ocean. At long length, someone made the obvious suggestion: Why not set up the machinery on shore? Immediately it seemed as if the whole scheme had been drawn into the realm of practicability. Surveys were made, engineering plans were drawn, and the Hydraulic Power Service in the French Ministry of Industrial Production has now been entrusted with the job of designing a great installation to be built at Abidjan on the Ivory Coast of Africa. Private investors are interested, and the French Government has allocated funds for the building of a pilot plant.

The plans call for the construction of a watertight concrete building containing two round rooms, one above the other, each just over 120 feet in diameter and nearly 30 feet high. In the floor between these two chambers the wheel of the turbine is to be installed. It is bladed, so that the passage of steam between the blades will set it whirling, and is to be mounted on an axle which will project through the roof where it will turn generators with a potential of 15,000 kilowatts. The plan is to bring warm surface water into the upper chamber, change it to steam, pass it through the turbine, and condense it in the lower chamber by cooling with water pumped in from a depth of some 1,600 feet and from a point about two and a half miles offshore. It was at first planned to bring the cold water in through a submarine tunnel, but this scheme has been abandoned as too dangerous. Instead, what is proposed is a long metal tube a little over eight feet in diameter, composed of rigid sections connected by flexible joints. A sample of such a tube, made up of three sections, has been submitted to extensive testing at Brest, and the report is that it works, and that the problems of getting it submerged and keeping it there have been satisfactorily solved. Finally, in order to reduce the strain on the pumps, which will have to keep enormous amounts of water circulating, it is proposed to build the plant in a very deep hole, far below the ground level, so that the building will be at about the level of the cold-water intake.

Such, in outline, is the projected installation. The scientists and engineers of the French government agencies who have been charged with planning it are convinced that they have solved the technical problems of converting the thermal energy of tropical waters into electricity. If the economic problems can be solved as well—and it appears that they may be—the possibilities that can open up are very exciting. One thermal-energy plant, on the scale eventually contemplated, could furnish several times as much power as a large hydro-electric dam. Located on the coast of Africa, it could supply current for all of Algeria and Morocco, could operate the trans-Sahara railroad, and most important of all, it could furnish the power that is needed to create oases in many parts of the desert. It may be that the desert scientists, desperately eager to drill down into the lakes they know lie far beneath their feet and bring up the fresh water that can turn sand dunes into productive farms, will not have to wait for atomic fuels or solar-energy machines. If the pilot plant at Abidjan is built and demonstrates that larger installations can be operated successfully, many other nations with coast lines along tropical seas may eventually follow the French example.

The oceans of the world are still essentially frontier territory, whose future contribution to the welfare of mankind we cannot yet estimate. But enough has been done to prove that there are incredibly vast reserves of food, of water, of certain minerals, and of power which have hardly been touched. What is more, the work that has already been completed along a dozen different lines has provided us with the knowledge and the technical ability we need in order to draw on those reserves. As with the undeveloped land areas—the tropics, the arctic regions, the deserts, and the marginal strips—the oceans are ready for man's use, and man is at last ready to begin to use them.

PART TWO

FOOD ENOUGH

There can be no doubt that some of the extra food we shall soon be desperately needing will have to come from areas not previously developed. Such places as tropics and deserts and oceans, however, have one very serious drawback: under the best of circumstances it will take time to bring them into large-scale production. And at this juncture of human events time is running short. The need of four thousand million people for food and the other necessities is not a problem that waits in the distant future to confront our great-great-grandchildren. It is upon us. Within fifty years it must be solved, else we may have no great-great-grandchildren. If men depend solely on the development of new territory, they may find that although there is world enough for all in the twenty-first century, there may still not be food enough.

There is, however, a great deal more that men can do, and it can be done by those who prefer to stay on their accustomed farms in the temperate zone. For the old home place, overcrowded and overworked as it may appear to be, is still capable of supplying immensely larger stocks.

The reason it does not do so at present is twofold: we have not made our cultivated land yield anything like what it could, and we do not manage to save for human consumption the whole of what it does yield. A little over two billion of us are living at present on the produce of three or four billion acres, and we are not living well. Yet if we would take care of those acres and of the food they can yield, we, and a great many more of our kind, could live very well indeed.

What prevents us from doing it? One factor is that in our capacity as food producers we have always been beset by enemies that constantly diminish our returns. The land itself is eaten by erosion both of water and of wind. Diseases strike at our plants and animals, ruining crops and decimating herds, and when they attack *our human bodies they drain away strength that should go into our labour. After we have gathered our harvests, parasites and predators gnaw at our granaries; and as if these losses were not enough, we are further impoverished by our own fumbling wastefulness.*

Yet most of this destruction is unnecessary. The day has long since passed when disease was a mysterious visitation; even the wasting away of the land is a process whose causes are understood perfectly well and whose prevention is common knowledge. Humanity is now armed with workable defences against all these enemies of production. As a matter of fact, a massive counter-attack has already begun, the grand strategy of which will be traced on many fronts in the succeeding chapters of this book.

The control of destructive forces is essential if we are to have enough to eat, and man's powers of control are vast indeed. But if we are to see modern man in his full stature, if we are to glimpse something of the gigantic creative genius that is in us and that will remake our world, we must look also to our increasing control over the very processes of generation. For twentieth-century man has reached into the laboratory of nature where the stuff of life is born, and by altering, substituting, and generally interfering he has wrought fruitful changes in nature's products. He has become able not merely to grow two blades of grass where there was but one before; nature, at his bidding, has been forced to yield him such "unnatural" bounty as five and six and seven heads of wheat on a single stalk. And this is but one in a vast number of triumphs that have already made it possible to double and triple the yield from our cultivated land. It is one detail in a complex pattern of endeavour, which, if wisely pursued, can bring abundance to all the people of this earth and thus usher in a totally new era in human history.

VII. ALL THE RIVERS RUN INTO THE SEA

It is an odd fact that one of the indispensable elements in successful farming should also be the most treacherous enemy of farm land. Water we must have if we are to grow any crops; and this is such a simple statement of the obvious that one may accept it without realizing what a complex and precarious balance of forces is necessary before the life-giving water can actually bring life to planted fields, nor how easily the balance can be upset.

For it is not enough for the farmer to have water. He must have it in exactly the right amount at the right time. So much and no more must soak into the soil; so much and no more must drain away; so much and no more must evaporate. If all these things do not happen according to schedule, crops and land are in for trouble. Everyone knows that too little water makes a desert, regardless of the fertility of the soil. But too much can make something worse than a desert. In the tropical jungles water brings death to the soil instead of life. Under the steady downpour of the rains, the minerals and other nutrients in the earth are leached out, and there is little left to feed plants. Standing water makes swamps, fit for nothing more helpful than mosquito breeding. Running water chews and tears at the earth, scouring away the thin layer which is all we can use and dumping it irretrievably into the sea, with a destructiveness that has always seemed to human beings overwhelming. It is no accident that in all early literatures the most often repeated story about the terror of natural calamity is the account of a flood.

Mankind has been attempting to fight back, of course, since the time when Adam delved; and although he took up that occupation only some two hundred millenniums after his first appearance on this planet, his history as a farmer is still rather ancient. Dykes, channels and irrigation systems all designed to break the force of floods and convert the destructive waters to human use, still survive as landmarks of one of the earliest of the many creative revolutions men have brought about on this planet. They represent a mighty attempt to seize control over a hostile environment, the first large social achievement of humanity. It was this work that created a Garden of Eden in the lower Tigris-Euphrates

Valley and provided the economic base on which the cradle of human culture rested.

Since the attempt to control running water goes back to the very foundation of the first civilizations, it is rather surprising that such control is still, at this late date, a *potential* instrument of abundance whose future possibilities are much greater than its past use. Nevertheless, this is true. Despite our long acquaintance with the problem, and our long-standing knowledge of the basic means of its solution, most of the rivers of this earth still flow unimpeded and unused into the sea. River control is one of the major instruments we can use to increase our production in the near future because, in the first place, there is so much of it to be done.

But there are more cogent reasons than this. Engineers have a better knowledge of the necessary skills than they have ever had before and better tools to work with, and contemporary civilization is rich enough to furnish the capital for large-scale undertakings. With the discovery of nuclear fission man has found a tool that may give him the Faustian power to "turn rivers from their customed course" with a fraction of the energy he once had to expend. Finally, there is now on one American river a nearly perfect example of complete valley development that can serve as model for hundreds of others.

The Tennessee Valley Authority is the greatest story of water control in the world. When the attempt to cope with depression was pulling us up to our tallest stature as a nation we in the United States undertook a project which was at that time unique. The world had seen many flood-control schemes, some of them quite extensive and highly successful. The large dam equipped with turbines for generating electricity from the energy of artificial waterfalls was already a commonplace of engineering. Reforestation for the protection of watersheds, traffic improvement over long stretches of waterway, the changing of a stagnant agrarian economy into a healthy combination of agriculture and industry—all these had been done in one place or another long before TVA was thought of. Even the dynamic concept of democratic public enterprise, which is the bedrock on which the success of TVA is founded, was by no means radical or even new. We ourselves had practised it in other directions for more than a hundred years. What made TVA unique, and still makes it, for the rest of the world, the most praiseworthy achievement of the American genius in this century, was the harmonious combination of all these elements into a unified plan affecting an entire geographical area.

No detail of that plan was wholly new, but the novelty of the plan itself took one's breath. All over the world men gaped in admiring astonishment as we took hold of a vast chunk of our country and by the sheer force of human control made it produce for us what no one had ever dreamed it could produce. Steadily, as the years have gone by, those same men have seen the results of our work and found them good. They have seen a river tamed, and the annual tribute formerly paid to its violence returned sevenfold upon the patient land. They have seen the network of power lines radiating farther and farther from the sources of supply, bringing light and energy to factory and farm. And as the people of the valley have risen to meet the challenge of new opportunities, these observers have seen what some call "human nature" changing into something more nobly human under the impact of the changing environment.

But perhaps what has made the deepest impression on a hungry world is the steady annual rise in agricultural productivity throughout the Tennessee Valley. With the land protected and with cheap electricity available at the touch of a button, with the coming of industry and better markets, methods of farming have improved. The grateful land has responded accordingly. Average yields have quickly outstripped the highest previous records, and they are still on the rise. To cite only one example, in the ten years ending in 1944, though the number of dairy cattle remained about the same, milk production went up 22 per cent.

The lesson of TVA has not been lost on the world. On hundreds of rivers all over the planet it has been and is being imitated. Indeed, if one wishes assurance that three billion people need not starve, no evidence is more conclusive than the widespread endeavour to control rivers and develop valleys to their highest potential productiveness. If you put your finger tip at random on a global map, the chances are high that you will find it resting on the outline of a country in which some large-scale project on the model of TVA is now in the process of being completed. While we in the United States formulate plans for developing the Columbia and the Missouri, expand the projects in California's Central Valley, and in all the multifarious works of our Reclamation Bureau and Soil Conservation Service continue to give the world its finest example of public agencies engaged in water-and-land conservation, governments and peoples in all parts of the world are hastening to bring their own rivers under control. And their undertakings are largely inspired by TVA.

Most of them tacitly recognize the influence of the American project in their very names. "Valley Authority" is a term now coupled with the names of many rivers to describe either an actual complex of dams and diversion tunnels and power stations and forestation work, or a dream that valley dwellers are hoping and struggling to realize. Even the self-sufficient French people are apt, in private conversations, to refer to their most ambitious water-control scheme as the "Rhône TVA," although the official name of its administrative organization is "The National Company of the Rhône." Called by any name, it is still modelled on the Tennessee Valley plan, and it is a fine example of contemporary work.

Preparations for harnessing the 500-mile Rhône River began as early as 1937, and the diversion tunnels at the site of the first dam were completed just as the Second World War broke upon France. During the terrible years of defeat and occupation the work was virtually at a standstill, but in

1946 it was begun again in earnest, and two years later the turbines began to revolve in the first power plant, at Genissiat near Belgarde. The six generators at this one dam alone will increase the electric supply of France by 7 per cent. The second dam, near Lyons, is also completed, and the French are going ahead rapidly with the entire project.

It is a very impressive job. When it is finished, twenty stations along the course of the river will be pouring much-needed electricity into transmission lines. Power in such quantities can transform French industry and the lives of both factory workers and farmers. Its impact on the French economy should be greatly invigorating. Indeed, several such projects might make France completely independent of Ruhr coal, creating a situation that could radically alter the economic and political balance of Europe.

Only slightly less important than the electricity to be derived from the Rhône is the development of the river into an inland waterway, able to carry vessels from the Mediterranean right up to the source in Lake Geneva. To accomplish this the French engineers plan a whole series of locks, which will lift the ships with their heavy cargoes more than a thousand feet up above Marseilles on the Gulf of Lyons to the foot of Mont Blanc in the Alps.

So far nothing has been said about using any of the water impounded by the dams for irrigation, and since great quantities will have to be kept flowing down the main course of the river to support the traffic that is planned for, it is not likely that much could be diverted. The Rhône Valley itself does not seriously need it. But there is an area nearby which cries out for controlled water. If you make a trip by bus or car from, say, Grenoble down through Digne to Nice, you will find your conveyance twisting along the sides of desiccated gorges through one of the most barren sections in Europe. Over large areas in the western slopes of the Maritime Alps, silt-laden streams cut and tear their way through deeply eroded land, while isolated villages, perched halfway up the steep hills, seem almost to pant for water. Such a village is Entrevaux, whose great drawbridge across the chasm to the highway is its only connection with the outside world. Yet the massive walls that surround it, coming almost together at the back of the town and continuing along a narrow corridor on up the mountain to a medieval castle near the summit, are eloquent testimony that Entrevaux was once a thriving centre of what must have been a good agricultural district. It is to be hoped that when the power needs of France are more nearly met, the French people will take in hand the rushing streams of the Maritime Alps, for the electricity and the irrigation water which they could supply, to say nothing of the erosion that could be eliminated, would bring new life to a large section of the country.

An interesting feature of the Rhône project is the way in which it is being financed. Of course, as in all other hydroelectric power installations, the cost of the great dams will be eventually repaid by the sale of power, and the traffic tolls will make the system of locks self-liquidating also. But the capital initially required to build such things is very large, and the French have worked out an interesting combination of capitalist and socialist organization to amass this capital. Unlike TVA, the National Company of the Rhône is not set up with national funds alone. It is a corporation in which the central government has invested heavily, but sizeable amounts of the total capital have also come from various municipalities in the Rhône Valley, and from private investors. The fact that canny French capitalists have put their money into the company is one of the surest indications that the development of the Rhône, like that of the Tennessee, is expected to be a highly profitable undertaking.

Because of the size of the initial capital outlay required, however, most such large-scale projects are entirely financed by public funds. How valuable they are as public investments is well illustrated by the experience of Puerto Rico. Since 1940 this little country has been engaged on a large electrification and irrigation project, and the plans are being carried out on a pay-as-you-go basis. When the authorities first planned what they could do with the 100-inch rainfall of their mountain regions if they could only bring it down to certain dry valleys, harnessing its energy on the way, they set up their own Water Resources Authority, and gave it control over an integrated system of some eighteen small hydro-electric and steam power plants already in existence. Then they built the first of the new dams, a comparatively small one. With money earned from the sale of power from that dam, they built another. Then, with still more capital, they started the Caonillas Dam, a mass of concrete 230 feet high, which, now that it is completed, stores up 50,000 acre-feet of water. Caonillas is only the first major construction in a planned series of dams and tunnels which will eventually control the falling water and turn its energy into electricity. When the force of the water is spent as it reaches the lowlands, it will be used to irrigate and reclaim some 25,000 acres in the Lajas Valley. This land is said to be potentially among the richest in the entire island, and it is expected that the water will turn it into an "Imperial Valley."

The eventual aim of the Puerto Ricans is to harness the entire potential of all their major streams by 1970, a consummation that would give them some 700,000,000 kilowatt-hours annually. In other words, the main incentive is the need for power, in order to develop local industries and attract those from abroad. But it all ties in with the food problem, nevertheless; for industrialization would certainly raise standards of living generally, and this rise would sooner or later be reflected in improved methods of farming and consequent increased production.

Puerto Rico is a tiny country and a poor one, and although it is in so sense "backward" so far as its people and their capacities are concerned, it must certainly be included among the under-developed nations. When such a country can, without outside aid, conceive and carry out such a development programme, then there is no reason for pessimism about similar schemes anywhere in the world.

And indeed, in this matter of river control the whole human family appears to have been seized lately with optimism. In Europe, at least, it may be part of the great wave of hope that lifted men's hearts when the Nazis were driven home. Norway, since the liberation, has launched a dozen or more hydro-electric projects. North of the Arctic Circle, Sweden has built the Harsprånget power plant, whose capacity is one-eighth of the country's total supply of electricity, and is now constructing the longest transmission line in the world to bring that power six hundred miles to industrial centres that can use it. Far to the south, Yugoslavia, in the full flush of her astonishing rebirth, is setting up power stations in such formerly neglected spots as Kotor in the People's Republic of Montenegro, and undertaking a huge river-control and land-reclamation project around Lake Skadar on the border of Albania.

Farther east, Iraq has obtained a loan from the International Bank for Reconstruction and Development, secured by her oil royalties, to finance the Wadi Tharthar Flood Control Project on the Tigris River. There are two highly significant points about this loan. In the first place, the Wadi Tharthar project is only the first step in an elaborate plan by which, if it is completed, the Iraqi hope to restore the productivity of what was once the richest agricultural land in the world. The Tigris-Euphrates Valley at one time supported a population of some thirty million; today it is almost completely desert, and five million people put such a strain upon its exhausted fields that most of them live in hunger all their lives. Lack of river control and irrigation is not the sole cause of this poverty, for unless something is done to change the system of absentee landlordship which curses the whole of the Middle East, the people will starve no matter how much water is controlled. But large public waterworks are a necessary element in reform.

The second fact of more than local interest about this particular loan is that it is the first the Bank has made to a Middle Eastern country. It should certainly not be the last, for the whole community of nations in that area stands in need of just such water control as Iraq proposes to acquire. Several of them now have in their oil royalties more than ample funds to finance a complete transformation of their lands, and it is to be hoped that at least a part of this new wealth will be used for constructive purposes.

More important even than the money, however, is the spirit of hopefulness that has swept through large populations in various parts of the globe as a result of political changes following in the wake of the Second World War. There has seldom been a period when so many millions of people have first breathed the exhilarating air of independence, and have become convinced, rightly or wrongly, that their country belongs to them and can be developed for their better welfare. Wherever this has happened, one finds new nations and new governments busily planning to harness whatever rivers may flow through the land, in great development schemes that are intended to control and use all the available water. Again, most of these plans are modelled on TVA.

The new state of Pakistan, for example, fell heir to the Lloyd Barrage in West Punjab, and to its enormous irrigation system—the largest in the world—which covers 6,500,000 acres of land. One might think that with such an asset as this a nation in the first years of its existence would be content to do no more, at least until the economy could become more stable. But the Pakistani seem to realize that one of the best ways to create stability is to undertake further valley development. They are therefore planning the Warsak Hydel project in the North-East Frontier Province, with the object of transforming the entire province by irrigating the land and building industries to consume the electricity that will be produced. Nor do their plans stop here. In 1948 the Minister of Commerce announced: "It is now proposed to develop each valley or basin of

Pakistan on a unified basis, embracing a number of purposes like flood control, soil conservation, irrigation, power generation, navigation, and fish culture," and after this impressive list he added grandly, "to mention a few of the more important purposes"! One wonders what more can be done with a river. Yet when one notices fish culture prominently mentioned, one sees that the TVA model is still capable of elaboration.

Pakistan has already been able to start work on some of her other rivers because she is a participant in one of the great international development efforts of our time, the so-called Colombo Plan. This is an enormous programme designed for the economic betterment of a group of countries in South and South-east Asia, entered into primarily by a number of governments in the British Commonwealth of Nations. It is a co-operative undertaking, in which Great Britain, Australia, Canada, and New Zealand are sharing the burden with the countries directly affected.

In the area in which Colombo Plan projects will be carried out, one-fourth of the world's present inhabitants live. It includes the Commonwealth countries of India, Ceylon, Pakistan, Malaya, and Borneo; and in addition to these, Indonesia, Burma, Thailand, and the three small components of Indo-China. In all of them work in many fields is contemplated: in mining and industry, in transport and communications, in social services. But the major emphasis is on agriculture. If the Colombo Plan is carried out according to expectations, at the end of its six-year duration 13,000,000 acres of new land will be under cultivation, another 13,000,000 formerly dry acres will be irrigated and the annual food production of these Asian countries will have been increased by 6,000,000 tons.

The proposed financing of this great plan is an interesting example of the way modern nations are learning to work together internationally for the common benefit. The estimated cost of all the multitudinous projects that are planned is between five and six thousand million dollars. But the countries involved have not thought it necessary to amass this huge capital in its entirety before getting to work. They are arranging the financing of each project as it comes up. There is no common pooling of funds, and no hard and fast provisions as to exactly what each one of the members is to pay. In general, it is estimated that about one-third of the eventual expense of the whole thing can be raised locally in the countries where the actual work is to be done. The rest will come from loans and outright grants by the non-Asian countries, private investments, reciprocal arrangements among the participating governments, exchanges of skills and materials, and straight commercial loans obtained in the general world money markets. The United States, although a member of the Colombo Plan Consultative Council, has made no direct pledges of money, but the sterling nations are hoping that sizeable amounts of dollars will eventually flow into the Colombo Plan projects through such agencies as the World Bank, the Point Four programme, and private investors.

Since river control is fundamental to much of the work needed in Asia, several of the countries are giving it the central place in their national planning. Ceylon, for example, is concentrating on a series of dams on the Gal Oya River. With the aid of an American engineering firm construction has already begun, and the main dam, two-thirds of a mile long and over 150 feet high, is nearing completion. The entire series, when completed, will enable the Singhalese to bring under cultivation about a hundred thousand acres of jungle; a similar, but smaller, project on the Walawe Ganga River will irrigate another 40,000 acres of new land. India, also, is devoting much of her Colombo Plan activity to the control and development of her rivers. There are seven irrigation, flood-control, and hydro-electric projects scheduled in that country.

In addition to this great effort in South and South-East Asia, various members of the Commonwealth are engaged in similar work of their own, without benefit of the Colombo

Plan. Australia, in a burst of post-war energy, is working to attract and provide for millions of new immigrants to people some of her vast, undeveloped territory, and much of this energy is going into water control. The state of Victoria is at work on the Kiewa, constructing a series of dams and tunnels very like that proposed in Puerto Rico, which will bring water from mountain rivers and lakes down to the lower valley, with six power stations to harness the energy generated by its fall. South Australia and New South Wales are co-ordinating similar schemes of their own with this one in Victoria, and the intention is to bring electricity to every farm and factory and home in the three states. Even thinly populated Tasmania has several large-scale projects under construction, including one for creating a series of nine new lakes connected by canals on the Nive River.

Some of the most interesting work in the British Commonwealth is going on in the African territories. In the Sabi-Lundi Valley of Southern Rhodesia, for example, irrigation from the "TVA"-controlled rivers is expected to open up for cultivation half a million acres of the country's most fertile land, double the national output of crops, and make Southern Rhodesia a food-exporting country. In Tanganyika the ill-starred groundnuts scheme, by which it was once proposed to turn three million acres of wilderness into mechanized peanut farms, has been drastically revised and is now being undertaken as a series of much smaller, but practical, projects supervised and co-ordinated by the Colonial Office. At Kongwa, where 90,000 acres had been cleared under the original plan, only 24,000 acres are to be planted to crops, while the remainder will be made into grazing lands. The clearing of bush around Urambo is to be continued, with 60,000 acres scheduled for eventual cultivation. And in the Southern Province of Tanganyika it is now planned to clear another 60,000 in a programme that will be completed in 1954.

North of Tanganyika and Rhodesia, where the great

African lakes are shadowed by the fabled "Mountains of the Moon," the protectorate of Uganda has initiated a very comprehensive programme to meet the needs of its rapidly increasing population, a programme that includes not only many measures for the improvement of agriculture, but housing, tsetse-fly control, social services, and urban development as well. The Uganda project, that will probably have the greatest influence in the general development of Africa, however, is one which is really part of a vast programme to control the Nile, and it is connected with several other engineering works in other countries through which the river flows.

At Jinja, in Uganda, just north of the Equator, the first section of the Nile makes a great leap down the Owen Falls in the course of its passage from Lake Victoria to Lake Kioga. Here, at the Owen Falls, British engineers have started an installation which will generate power equal to that furnished by 400,000 tons of coal a year. In the dam that is now rising, six turbines are to be installed, with provision being made for the installation of two additional turbines at a later date. The electricity thus produced can play a vital role in the development not only of British territories in equatorial Africa but of the neighbouring French and Belgian colonies as well.

The generation of hydro-electric power, however, is only incidental to the main purpose of the dam at Owen Falls. Its primary function will be to enable man to regulate the level and the discharge of Lake Victoria, the second largest lake in the world and the most important reservoir of the waters on whose seasonal rise and fall the lives of twenty million Egyptians depend. Egypt, whose population has tripled within the present century, is desperately in need of more water for expanding the irrigated area in the Nile Valley. The water must come from the river, and it has been an extremely tricky problem for the hydrologists to figure ways of supplying more water to the upper valley without depriving farmers in the rich plain between Aswan and the delta. Now, however, a complex system of controls at various points along the course of the river has been projected, of which the increase in the waters impounded in Lake Victoria is the first.

Below the Owen Falls the Nile slows down, spreads, and grows wide and shallow as it enters Lake Kioga. It must traverse sixty miles of this muddy, weed-choked lake before it can flow freely again. All along its shores Kioga is a swamp filled with papyrus; farther out it is a shallow lake filled with rushes and weeds; miles of its surface are carpeted with the thick round leaves of the blue water lily. These plants are beautiful, but they cause a serious loss of much-needed water. It is not surprising, therefore, that there is talk of attempting to destroy the rank vegetation in Lake Kioga, for if the weeds and lilies were gone, the carrying power to the lake could be increased by over 1,000 million cubic metres. From Kioga the river flows through a corner of Lake Albert and over the Albert Falls, where again a dam has been suggested, this time to impound more of the water coming down from the mountains through Lakes Edward and Albert into the main stream.

North of the Albert Falls, and north of the boundary of Uganda, the Nile enters the plains of the Anglo-Egyptian Sudan, and here again a tremendous loss of water occurs. The river meanders slowly through the plains for hundreds of miles, finally spreading out over the Sudd swamps where it lies almost motionless under the burning sun before it finally reaches a downward slope sufficient to set it flowing rapidly again. It is reckoned that in the swamps of the Sudd the Nile loses by evaporation from 40 to 60 per cent of all the water it brings down from Lake Victoria and the towering Ruwenzori Mountains. A most important part of the Nile conservation scheme is the projected digging of a canal 150 miles long through which the river can be led to by-pass the swamps.

All these proposed works along the White Nile are designed to assure and increase the winter supply of water in the main Nile Valley, and if they are carried out they will certainly bring greater productivity to Egypt. Lake Victoria alone, if its level and rate of discharge can be controlled, could supply thirty-six times as much water as the reservoir that was created by the dam at Aswan. But the all-important flood of the Nile, on which much of Egyptian agriculture depends, comes not from the White Nile, but from the Blue, which flows down from the mountains of Ethiopia to join the White at Khartoum. The flood that comes down in summer and early autumn is the lifeblood of Egypt, without which there could be no agriculture in the valley, but it actually brings more water at one time than can be used on the land at present irrigated. Much of it must be allowed to pour itself wastefully into the Mediterranean, taking along sixty million tons of rich silt. Since some control over the flood waters would enable Egypt to spread it and make use of much of the water that is now wasted, a dam has also been proposed at Lake Tana on the Blue Nile, and if the Ethiopian government agrees to its construction it will doubtless be built.

Meanwhile, far to the south, proposals are being studied for building dams on the Zambezi River and on one of its tributaries, the Kafue. What makes this plan so interesting is the self-sufficient industrial complex it would make possible. The Zambezi is the boundary line between Northern and Southern Rhodesia. It happens that at the famous Wankie Colliery in Southern Rhodesia what is probably the largest deposit of coal in the world is being worked. Northern Rhodesia, on the other hand, is one of the largest producers of copper, its mines accounting for 12 per cent of the world ouput. The two Rhodesias also contain extensive deposits of chrome, and what is even more important, iron ore in great plenty.

All that is needed, apparently, to create in the Rhodesias an industrial complex rivalling that of such regions as the Kuzbas-Ural network is some economical means of bringing the coal and the ores together and supplying electric power for their transformation. Dams, especially the proposed one at the Kariba Gorge on the Zambezi, could not only provide the power, but could create inland waterways for cheap transport. It would seem that the problems are not nearly so great as those which existed in Siberia, where very long and expensive rail hauls are necessary. What such development could mean to these two landlocked territories in the heart of Africa, and indeed to the surrounding parts of the continent, is self-evident. As a result of the industrial base already existing, Southern Rhodesia has advanced to the very threshold of dominion status. If the strength of the Zambezi can be harnessed and added to the effort, the colony of Northern Rhodesia will not lag far behind its southern neighbour.

All these projects and proposals—and they are selected from many more in various parts of the world—are modelled, directly or indirectly, on TVA. They may be larger or smaller, the major emphasis in the plans may be on slightly different benefits the builders hope for, and the problems that must be solved in their construction may vary considerably from the specific conditions in the Tennessee Valley. But by and large, there is in none of them any radical departure from practices that have already been thoroughly tested. But there are two proposals now before the world that strike out into new directions, carrying the principles of water control and valley development into what are really new and untried fields.

The first of these is the well-known plan for a Jordan Valley Authority in Palestine. The chief proponent of the idea, Dr. Walter C. Lowdermilk, is an American reclamation expert who knows the TVA intimately, so that an indebtedness to the Tennessee project is inherent in it. But there is an extraordinary new feature, and this is the proposed diversion of water, not only from a river, but from the open sea.

Dr. Lowdermilk has said that the idea first occurred to him when, in 1939, he was engaged in making an aerial survey of Palestine. What caught his attention was the fact that the whole Jordan Valley, which feeds its waters down to the insatiable depths of the Dead Sea, lies far below sea level. Yet the coast of the Mediterranean is at some points less than thirty miles away.

He had probably thought before of the possibilities of diverting the Jordan for the irrigation so badly needed in Palestine. But such diversion would cause the Dead Sea to dry up, and it would also furnish little electricity. Looking down into the great rift of the Jordan Valley, and seeing how its walls plunged downward 1,292 feet below sea level to the surface of the Dead Sea, Lowdermilk saw a possible solution to the problem. If a canal were dug across the coastal plain, and a tunnel through the hills that border the rift, sea water from the Mediterranean could be dropped down into the lower valley. The fall is great enough to provide all the electricity Palestine needs, and at the same time the new salt "river" could replace the Jordan in maintaining the level of the Dead Sea. This would permit nearly all the sweet water of the Jordan to be used for irrigation, to nourish thousands of acres of now barren land. The Sea of Galilee, with its inflow reduced to a trickle, would shrink into a small lake, giving up 20,000 acres of its former bed to cultivation.

This, in brief, was the outline of the proposed Jordan Valley Authority, as it existed up to the time of the partition. It had by then been studied and elaborated in considerable detail; it was determined, for example, that at least 750,000 acres could be irrigated with fresh water from the Jordan and its tributaries, that more than 800,000,000 kilowatt-hours of electricity could be generated yearly, and that the cost of the work would run to $250,000,000, a sum that could be entirely repaid in fifty years, with interest at 3 per cent.

Since the partition of Palestine the new government of Israel has had to modify the plans considerably, because large parts of the territory involved now lie in the kingdom of Jordan, in Syria, or in Lebanon. It is to be hoped that the interested governments can eventually work out some kind of co-operative effort, perhaps using ideas and methods from such a plan as the proposed Hylean Amazon project, to create an international JVA, for all would stand to benefit from it. But although the necessary international agreement has not yet been reached, the Israeli have not abandoned the idea. Five alternative modifications of the original plan have been worked out, each involving work which would be done entirely within the borders of Israel. Interestingly, whichever is finally adopted, it will be tied in with the work already undertaken to bring water to the Negev. Pipe lines are now being laid which will carry southward to that desert country fresh water from the Yarkon near Tel Aviv, and the day is not far distant when the Biblical Wilderness of Zin will be a richer agricultural area than it was when the Nabataeans built their dew mounds. Indeed, every water-control scheme now being developed in Israel, whether it involves swamp draining or drilling deep wells or wadi cultivation, is being devised to fit eventually into one nation-wide system, of which the ultimate Jordan Valley Authority will provide the cornerstone.

There are enormous difficulties, of course, but they are political and financial, rather than technical. Israeli scientists estimate that if the political situation were eased and the necessary quarter-billion dollars were available immediately, the entire work could be completed within ten years at the most. Things being as they are, they still intend to have their Jordan Valley Authority, and all the interconnected water-control projects which can make their country support a far greater population, well before the end of the present century.

Lowdermilk has said that even as early as the time when Jewish colonists were allowed to take up only 7 per cent of the land of Palestine they had "already done the finest reclamation of old lands that I have seen in four continents, indeed the finest reclamation work of modern times," and he went ahead to point out why: "They are working out a *lasting* adjustment of a people to their land." This is the significant fact about almost any complete valley-development programme, whether it be in Israel or in Africa or indeed in the United States. Land and water, properly managed, are really inexhaustible assets. Cultivated land does not "wear out"; it is "worked out" by general mismanagement, which often includes as its most destructive element the water erosion that man himself permits. Proper use of water makes possible proper use of the land, and the whole complex of flood control, irrigation, reforestation, and hydro-electric power that goes to make up any complete valley-development plan is no mere stopgap measure. On the contrary, it provides the base for a permanently productive agriculture.

It is the search for a permanent solution to the problem of unusable land that has prompted all the many adaptations of the TVA plan. Most of these, as I have said, follow the same general pattern, with the exception that the proposed Jordan scheme involves using sea water to produce the power. Far to the north of Palestine, however, there is another proposed project which has certain new features worth mentioning.

The Russians have long had in mind the harnessing of their principal European river, the Volga, both for irrigation and for the production of electricity. Plan after plan has been drawn, but they have all had to be abandoned because they came up against a hard and unavoidable fact: the Volga empties into the Caspian Sea, and any tampering with the river would lower the level of that vitally important waterway. The northern reaches of the Caspian, where both the Volga and the Ural debouch, are shallow, and if the water level should fall only a little, cities and ports like Astrakhan and Guryev would be left stranded high and dry. In that event, oil from Baku would have to go by a long and difficult rail haul in order to reach Moscow or Kuibyshev or the new industrial cities in the Ural Mountains. Since the harbour at Baku is also shallow, even that important port would be isolated. It was at one time thought that the problem could be solved by diverting the Don River through a canal to Stalingrad and the lower valley of the Volga, but the Don waters are needed in their own valley. Until recently, all the Volga plans have seemed impossible.

In 1950, however, the Soviet government announced that it intends to build two dams on the Volga, one at Kuibyshev and the other near Stalingrad. The power stations proposed at these two sites, it is said, will together generate 20,000 million kilowatt-hours a year—just under the total 1946 production of all power plants in Sweden and Switzerland combined—and the water will then be diverted to irrigate some thirty million acres. The calamity this diversion would bring about in the Caspian area is apparently to be avoided, and in a rather unexpected way. For at the same time that the Volga project was announced, plans were also published for bringing one of the rivers of Central Asia into the Caspian.

This river, the Amu Darya (or the Oxus, as it was called in classical times), flows northward 1,400 miles from its source in the Hindu Kush to the Aral Sea, which it enters through a long delta. On the way it cuts through the black sands of the Kara Kum, a barren land that is said to be second in size only to the Sahara among the deserts of the world. Geologists have established that in earlier ages this river followed a different course; it turned westward before reaching the Aral and poured its water into the Caspian. All along its course what is now desert was well-watered farm land, and archaeologists have discovered that here men grew crops and built thriving communities, which traded down the river and across the sea with other communities in Europe and Asia. Well above the ancient turning point of the river, the modern Turkmenians have already dammed the Amu Darya and used some of its water to irrigate the land on which they grow their famous long-staple cotton.

What is now proposed is to turn the lower river back toward its ancient course, and let it once again enter the Caspian at Krasnovodsk. By itself, this is a dream which has been in Russian minds since the time of Peter the Great, who sent engineers to study its feasibility, but it has never been attempted until someone grasped the brilliant conception of using it to solve the Volga-Caspian problem. Although to shippers in Baku the main advantage of this now-proposed diversion may seem to be that they can stop worrying about the falling water level, to the people of the Turkmenian republic the important thing is that they can hope to irrigate some three million acres of now-useless land. Here they think they can increase the cotton production of their country to seven or eight times its present figure. In addition, they believe they will get several million acres of new pasture land, on which they can develop further another of their important industries, the breeding of caracul sheep.

Here, then, is an expansion of the basic TVA idea, in which work on two rivers, widely separated geographically, is to be co-ordinated so that a variety of local and national objectives can be attained. The turning of one river solves a problem so serious that it had defeated all attempts to harness the other, and the control and use of both, it is hoped, will make invaluable contributions to agriculture and industry. The work on both these projects has been started; during 1951 the Soviet press and radio frequently featured eyewitness descriptions of the preliminary work on the great dam at Kuibyshev and of the canals which are being dug in Turkmenia.

There is still a third possible undertaking which may some day be integrated into these two. As far back as 1871 a Russian scientist named Demchenko proposed what his generation regarded as a fantastic notion. Having observed that all the rivers of Siberia run in what seemed to him the wrong direction, flowing uselessly into the Arctic Ocean, whereas to the south are barren regions that lack none of the essentials for agriculture except water, he proposed a scheme for turning some of those rivers around. His idea was, roughly, that if the Ob and Yenisei rivers could be made to flow southward to the Aral and even to the Caspian, the geography of western Asia would be greatly improved. He pointed out that irrigation on a vast scale would be possible, and that it would turn the barren lands north and west of the Aral Sea into rich farms. But while his generation admitted the desirability of such transformations, the proposals for achieving them were dismissed as completely impractical.

Demchenko's scheme has been revived of late years, however, and an entire plan has been worked out in considerable detail by a scientist named M. M. Davydov. This man is a practical engineer, native to the region that would be involved in the scheme, and with years of experience in responsible positions. He was second-in-command of all Soviet water-power projects during the period when the great Dnieprostroy dam was built, a project on which many American engineers, trained in TVA methods, were employed. Davydov also had the same position on the Greater Volga Project when the canals and dams were built near Moscow before the Second World War. Furthermore, since Demchenko's time the science of engineering has developed so much that it is no longer possible to dismiss grandiose schemes as airily as it once was. Developments in other fields, particularly in arctic transport, have added new elements to the original dream, and what emerges today in the Davydov plan is a serious proposal of such magnitude that it demands serious consideration.

What is proposed, first, is that a dam be built on the Ob River below its junction with the Irtysh. Such a dam would cause the waters of both rivers to back up into their valleys. This would create the largest fresh-water lake in the world, with an area four times that of Lake Superior, for both rivers flow through low, nearly flat land for long distances. The land it would cover is at present swamp, so that its submergence would be no great loss.

Up above its confluence with the Ob, the Irtysh is enlarged by several tributaries which flow northward into it from the direction of the Aral Sea. Between the sea and the main river the land is mostly a great plain, the watershed being only some hills of a few hundred feet elevation. The basic idea in the Davydov plan is to cut a deep canal through those hills, reversing the direction of flow of the Irtysh tributaries so that water from the newly created lake would drain into the Aral. Another canal on the opposite side of this sea would carry the water on to the Caspian, probably through the proposed Amu Darya diversion, and thus convert the salty Aral into a fresh-water lake. Some of the southward-flowing water could of course be diverted before reaching the Aral, and used to irrigate the now-barren country.

Essentially, this is the Demchenko proposal, but there are some other features that Demchenko did not think of. At his time the Arctic Ocean was universally considered a frozen waste, and the idea of using it for transportation was scoffed at. Today the picture has been radically altered. The Arctic in summer from Archangel to the Bering Strait is a usable waterway, which is doing for the whole region along its shores very much what overland transportation routes did for our West. It is evident, therefore, that if a navigable waterway can be constructed from the Ob-Irtysh southward clear to the Caspian, such cities as Baku, Krasnovodsk, and Astrakhan will become ports from which cargoes can be sent by water to Vladivostok, and indeed, right around the world. Such a waterway would also, of course, provide a direct connection from either north or south with the Trans-Siberian Railroad, which would cross the new canal at a point between Sverdlovsk and Omsk. Thus the Ural-Kuzbas industrial complex would have a new and inexpensive outlet for shipping its products in either direction and for receiving the products of other regions.

As a result of all these considerations, the Davydov plan includes also the construction of locks wherever they may be needed along the route. In addition, it provides for connecting the Yenisei River with the great lake to be formed in the Ob-Irtysh Valley, to bring into the transportation network the thriving new timber-exporting town of Igarka on the lower Yenisei and the arctic ports near its mouth.

Although the Davydov proposals have been widely discussed, the Soviet government has so far made no public announcement concerning any plans for carrying them into effect. Nevertheless, when the Amu Darya diversion into the Caspian is completed, the attempt to connect both Caspian and Aral with the Arctic would seem to be a logical next step. The Soviet Union has made widespread efforts to reclaim land by irrigation. It does not seem likely that the barren regions between the Aral and the Ob-Irtysh Valley will be left unwatered indefinitely, provided the Davydov plan is considered feasible. Another factor which would indicate that the Soviets ought, at least, to be considering Davydov's ideas very seriously is that irrigation in this area would no doubt reduce the dangers of drought in European Russia, and would thus increase the chances of success in their tree-planting and land-improvement projects in that region.

Sceptics, if they are unaware of recent developments in engineering, may still be inclined to scoff at the Demchenko-Davydov idea of making rivers flow backward, and since this is the central feature of the proposals, they may think the whole thing impossible. But this notion of completely reversing nature's geographic scheme is not a Soviet invention. American engineers have already done it, by a different method from the one the Russians propose, in three separate localities. They have not only made rivers flow backward, but *uphill* as well. At three places in the West, a total of eleven million gallons of water per minute is being lifted higher than a skyscraper and set flowing in the opposite direction. It is as if a volume of water twice the size of the Potomac were picked up as it passes the famous cherry trees, swung far up over the top of the Washington Monument, and sent back toward West Virginia whence it came.

In America the trick is done by gigantic pumps. In the greatest of all water lifts, the west-bound Columbia River is first caught up behind the Grand Coulee Dam; then a part of its waters are pumped up over the mountains to a dry channel through which an ice-age river once flowed, and sent down it to irrigate over a million acres in the Big Bend country of eastern Washington. The surface of Grand Coulee reservoir is about 350 feet above the Columbia River bed, and the twelve pumps lift the water another 260 feet to start it in its new direction.

In the enormous Central Valley water project in California, one of the many geographic obstacles the engineers had to overcome was the fact that the thirsty but extremely fertile San Joaquin Valley is a fairly high basin surrounded by hills and mountains. Yet the only available water which might be used to supplement the irrigation systems already in the valley was flowing down the Sacramento River into San Francisco Bay, outside the hilly barrier. The difficulty was solved by installing the second largest pumping plant in the world at Tracy, to lift Sacramento River water 200 feet into the Delta-Mendoza Canal, through which it flows into the San Joaquin River system. This additional water in the valley permits a backward turning of the upper reaches of the San Joaquin itself. A large part of its northward-flowing water is impounded and sent back south some 150 miles through the Friant-Kern Canal to irrigate land near Bakersfield.

High up on the western slope of the Rockies is the third of the great pumping plants, the Granby. As one unit of the complex Colorado-Big Thompson Project, the three

Granby pumps will lift a sizeable river of water 186 feet up the mountain to the intake of one of the modern engineering wonders of the world: the thirteen-mile Alva B. Adams Tunnel. The longest irrigation tunnel ever constructed, this man-made conduit cuts through the Continental Divide to carry the western waters to some 700,000 dry acres on the eastern slope.

Compared with such works as these, the digging of canals and tunnels such as the Russians propose seems a fairly simple undertaking. In any event, the Davydov plan is worth recording as another example of the kind of thinking that has been inspired in twentieth-century minds by the combination of urgent need and technical skill. In project after project, all over the world, humanity has been demonstrating this skill in complete river and valley development ever since TVA set the basic pattern and proved that it could be achieved. Whether there are other regions in which something on the scale of the Ob-Yenisei-Caspian-Volga complex could be usefully worked out is a matter for future engineers to determine. There can be no question, however, that there are hundreds of regions in which the basic TVA principles can and should be applied.

To take one example, Turkey is in dire need of both irrigation and power, yet her hundreds of small rivers are as yet unharnessed. and their eroding force is constantly destroying more and more Turkish farms. Greece is in similar need; so are most of the countries of Latin America. In fact, in almost every under-developed country of the world, and in many that have advanced to a high stage of industrialization, are rivers that await the planner and the engineer.

In this needed work, international sharing of knowledge and equipment and experience is of fundamental importance. Not long ago, for example, the U.S. Bureau of Reclamation opened in Denver its new Engineering Centre, an institution devoted to research into technical problems connected with its work. Its primary purpose, of course, is to aid the Bureau to carry out more efficiently its manifold duties in protecting and conserving the productive resources of its own country. But under the so-called Point Four Programme, the Bureau is extending its services to other lands. It is now sending its own experts to foreign countries to give on-the-spot technical advice and assistance with engineering problems. At Denver it has set up training courses for young engineers, where students from many lands may study American methods at the expense of their own governments. And finally, the services of scientists working in the laboratories at the new Centre are made available to foreign governments at moderate cost for the purpose of making tests and doing research in connection with their own projects.

How all this works out in practice is very well illustrated by a job which the Bureau completed for the government of India early in 1951. One of several large water-control projects being undertaken in India within the framework of the Colombo Plan is that on the Kosi River in the south-eastern corner of Nepal. At a point on this river a few miles from Darjeeling, the Indians propose to build a dam 785 feet high, which will be the tallest in the world, 57 feet higher than the Hoover Dam on the Colorado river in the United States. The Kosi Dam will be extraordinarily useful. By eliminating the present flood areas, it will decrease the incidence of malaria and other diseases that now take a heavy toll in the region; and the water impounded by the dam will irrigate four million acres of land (an area larger than Connecticut and Rhode Island together) which can then add an estimated million tons of food each year to India's supplies.

The construction of this great dam, however, involves certain very unusual problems. The Kosi carries one of the largest silt loads of any river in the world: its silt rate is 397 acre-feet per 100 square miles of catchment area, as compared with a normal rate for river basins in the United

States of only 75 acre-feet. Furthermore, the region in which this dam is to be built is one in which earthquakes are quite common, the dam site itself having been shaken on at least four recorded occasions. Modern engineers do not regard either heavy silt rates or earthquakes as insurmountable obstacles to dam building, but they are factors which require very careful designing.

The Indians drew up their designs for the dam, but before beginning construction they sent them to Denver for what is called a "load and stability analysis." Neither party to the agreement knew in advance what such an analysis would cost, but the Indian government deposited $30,000 with the State Department as an advance payment on the Bureau's eventual bill, and a contract was drawn.

The analysis was made, as it turned out, for a very small part of the Indian government's deposit. But the contract was not concluded at that point, because in the course of their initial study the scientists at Denver made a very important discovery. They found that although the Indian designs were good, it was possible to change them in such a way as to make an equally strong dam at a saving of some 900,000 cubic yards of concrete. This would mean a saving to the Indian government of approximately ten million dollars. Naturally, they were asked to furnish complete details.

The total cost of all the work done by the Bureau for the Indian government, including both the original load and stability analysis and the redesigning, was only a little more than half the $30,000 originally advanced, so that at the completion of the work a voucher for the return of the unused portion was forwarded for remittance through the State Department. And the reason given for the exceptionally low cost is illuminating. At the time these tests were made, a group of young Indian engineers were studying at the Engineering Centre, on scholarships provided by their government, and they were naturally assigned to help with the work. According to the report of Acting

Reclamation Commissioner G. W. Lineweaver, the cost was low "because of the excellent assistance by the Indian trainees." It is significant that a few months after this work was done, the Indian government entered into a long-term contract with the Bureau for the continued use of the Denver facilities. This is the first such agreement with a foreign government, but it may certainly not be the last.

Complete river and valley development is one of the most potent instruments mankind can use to create abundance. If men and nations will use it together, co-operatively pooling their resources and sharing their skills, they will reach their goal much sooner.

VIII. NETS TO CATCH THE WIND

NEXT TO running water, the great eroder is wind. It does not often dig out gullies and scrape soil down to the bedrock with the same suddenness as a flood, but over a period of time it can do just as much damage to unprotected farm land. Wind blowing across an open ploughed field lifts the soil particle by particle and tosses it away, until finally the topsoil is gone and the field is worthless.

After the American drought of 1934, soil on the surface of thousands of acres of plains country was snatched up by the driving westerly winds and scattered as dust far and wide over the eastern states and even out into the Atlantic Ocean. To anyone who witnessed a part of that great devastation, the sight of the land being picked up from under one's feet and hurled almost with the force of a sandblast was an unforgettable demonstration of the destructive power of uncontrolled nature, terrifying in its blind wantonness. As earth itself rose up and swirled around one's face in a choking cloud, it seemed as if all the solid values of human life were dissolving in the rush of the wind.

For weeks and months during that terrible winter, farmers in the Dust Bowl states stood helplessly in their fields, watching the wind tear away the foundations of their livelihood. When it was finally ended, the hope that keeps us living had almost been blown out of men's souls. Many people believed, after this demonstration of nature's wrath, that the possibility of productive agriculture in the windy regions was a hopeless dream. The plains area, it was said, had been created by nature for the sole purpose of providing grazing range. The natural cover was tough, thickly matted grass, over which the winds might roar harmlessly without disturbing the soil. When man brought his traditional methods of agriculture into the endless pastures, ploughing away the natural cover and turning up the bare earth to the wind's force, he violated natural laws. The Dust Bowl, with all its attendant misery, was simply the punishment any lawbreaker ought to expect.

Fortunately, men have found out through centuries of battling with nature that when a natural law interferes with human striving and prevents the satisfaction of human needs, it is usually possible to create a situation in which other laws come into effect: laws which nature herself must obey, and which serve to further man's desires instead of frustrating them. It is not possible to prevent the wind from blowing; but there are other things besides a thick cover of native grass that will prevent the blowing wind from destroying farm land.

The experience of 1934–35 forced Americans to search out these alternative methods of control, and to attempt to apply them. President Roosevelt, looking over reports of soil erosion on the Great Plains, is said to have inquired whether it might not be a good idea to plant trees as windbreaks and soil protectors. He is credited with remarking at the time, "Man cannot change all the forces of nature, but he can modify his own surroundings," a sentence which, whether it was actually uttered or not, might well be the theme for all human wind-control efforts before and since. From this interest of the President came the great project that stirred up so much political dust and settled so much of the actual dust that was blowing across the prairies.

The basic idea was by no means new. Men had long known some of the values of planting trees, and by the time the American project was started a great deal of valuable information was available concerning the three principal types of plantings: forest areas, windbreaks, and shelterbelts.

A forest area is just what the name implies, a massed planting of trees over a large area to form a man-made forest. A windbreak is a fairly short, but thick and wide, planting of trees and shrubs. It is used generally around the farm buildings to give protection to kitchen gardens, to houses, to livestock, and to people as they go about their work and play around the farmstead. The shelterbelt, on the other hand, is a long and comparatively narrow strip, sometimes only a hedge or a single row of trees, that is planted around the edges of open fields to protect crops.

Windbreaks are quite ancient: from the earliest times, apparently, men settled in windy country have put hedges and other growing walls around their gardens and have set out wood lots and small parks of trees around their homes. For centuries they have known in a vague way that such windbreaks were valuable as well as beautiful; peasants in the Middle Ages probably realized that more of their cattle would live through the winter, just as more people would, if they had some shelter against the cold wind. Quite recently this kind of folk wisdom has been given a scientific proof in a series of experiments in the northern States. In one of these, two herds of cattle were fed exactly the same winter rations, but one was kept in the protection of trees and shrubs while the other was left in an open lot with a small shed. During a mild winter those cattle that had tree protection made average gains of 34.9 pounds more than those in the open lot; in a severe winter they lost 10.6 pounds less. In another experiment two herds were weighed and then put to pasture, one in an open field and the other in a field that had some natural protection from trees and shrubs along a stream. After a three-day blizzard, the two herds were weighed again. Both had lost weight during the storm, but the cattle in the partially protected field had lost an average of 30 pounds less than the others.

It took mankind much longer to realize that field crops, like people and livestock, might benefit from some protection against wind. The systematic planting of shelterbelts around fields originated toward the end of the eighteenth century in the Volga Valley in Russia. A group of German Mennonites, fleeing from religious persecution in their own land, had been encouraged by Catherine the Great to settle there, in the hope that they might teach the Russian peasants some of their habits of neatness, frugality, and industry. As it turned out, they taught both the Russians and the world something more specific, for it was they who, in the attempt to subdue the winds in their new environment, planted the first shelterbelts in 1792.

It took the Russians nearly a century, however, to learn the value of the Mennonites' lesson. They had been experimenting with massed plantings of trees in the steppes ever since 1696—in that year an attempt was made to start an oak forest by planting acorns near the Sea of Azov—and for a long time they stuck to their own ways. During the succeeding century and a half they planted forest areas on thousands of acres, using hit-or-miss methods that were never very successful, although a few of these old plantations that were incorporated into government forests still exist. The first really systematic afforestation programme in Russia was the so-called "Great Anadole Experimental Forest," begun in 1843. Still another forest area, it covered about 375 acres, and created quite a bit of excitement in its early stages, but most of the trees were eventually destroyed by insects.

During the latter half of the nineteenth century Russian foresters gave increasing study to the problems of afforestation in relation to wind control, and by the 1890's they had made two contributions that were to be of considerable use both to themselves and to others. In the attempt to establish oaks, they had tried combining them with other faster-growing trees in order to give needed shelter to the delicate oak seedlings. Finally, they stumbled onto a pea-like shrub called caragana, and discovered that it did a far better job of protecting very young trees. In 1893 their great forester, G. N. Vyssotsky, gave a scientific justification for this use of shrubs in tree plantings, and the principle, as well as the caragana shrub itself, has been adopted in many countries, including our own.

The second contribution was the eventual adoption of the Mennonite shelterbelt and the proof of its value. Shelterbelts were planted experimentally on the Crown estates in 1872. By the end of the century, as a result of widespread tests, the Russian foresters had proved that the long narrow strip of trees is far superior to the forest area as a means of combating wind damage. A planted forest is as useful to man as any natural one, of course, but although it may be many miles across, it gives no more protection to an adjoining field than a narrow belt and its effect does not extend any farther.

In the meantime, tree planting for a variety of purposes had been by no means confined to Russia. In the United States the opening of the western lands had brought farmers, accustomed to the wooded eastern states, into great, treeless plains, and those settlers had begun an afforestation effort that was to culminate in the Great Plains Shelterbelt Project. Records exist of plantations in the Nebraska Territory in 1854, and not only records but some of the trees that were set out at that time. Almost from the beginning, such enterprise on the part of the settlers was encouraged by government. Within four years after admission to the Union, Kansas in 1865 passed the first tree-bounty law, offering her citizens a definite monetary reward for their efforts to establish trees. Nebraska and the Dakota Territory gave a similar inducement in 1869 with tax-exemption laws that favoured the planters of trees. By 1872 the growing public interest in afforestation of the plains found expression in the celebration in Nebraska of the first Arbor Day, a custom that has since become nationally observed.

The federal government entered the picture with the passage of the Timber Culture Act in 1873. Under this law a homesteader could obtain a clear title to 160 acres by planting 40 acres to trees. As a way of stimulating protective plantings it was less successful than the various state laws, but it is significant as the first recognition that wind control on the plains and prairies is a problem of national interest and concern, and as giving a precedent for the governmental activity in 1934.

In addition to this legislation to stimulate private action, the government had for many years before President Roosevelt's query been working on afforestation on its own, through the U.S. Forest Service. One of its most successful jobs had been done in the northern Great Plains, where the staff of an experiment station had planted a forest area, thousands of acres in extent, on the bare sand hills near Mandan, Nebraska. This project was begun in 1914, and twenty years later it was a flourishing stand of trees, already known as the Nebraska National Forest.

Besides the American background, foresters in 1934 could draw on a wealth of experience that had accumulated over the years in other countries. As early as 1901, the Canadian Prairie Provinces had inaugurated a great programme designed to protect crops against very much the same conditions as are found in the northern plains of the U.S. By the time it was completed, the Canadians had planted 211,000,000 trees and had amassed a great deal of evidence on their value. It was widely known that the Danish people had planted mile upon mile of shelterbelts in the province of Jutland, and were getting good harvests on land where productive agriculture had been considered an impossibility.

Through wise afforestation, thousands of acres of wasteland had been reclaimed in the Landes department of France, and there were large-scale plantings in Hungary, in Italy, and elsewhere. In Russia, where much pioneering work had been done, the afforestation of the steppes had been seriously retarded during the revolution. But after the great famine of 1921 interest in drought prevention was aroused again, and the Soviet government began to urge the planting of more trees. During the first Five-Year Plan (1928–32) the area of planted shelterbelts rose from 5,000 to 35,000 acres, and the second Five-Year Plan provided for the planting of 865,000 acres around cultivated fields and orchards.

Thus the Great Plains Shelterbelt Project, which was launched by executive order late in 1934, was by no means new. It had, however, three features which were new to American tree-planting efforts. During some eighty years of experience it had been borne in on thoughtful observers that the successful establishment of trees on the western plains and prairies depended on the use of professional skill. There was no comparison between the health and vigour of trees planted by the Forest Service and those set out by untrained farmers. It is no easy thing to get trees to grow where they have never grown before, and one of the reasons the Timber Culture Act had not produced more successful plantations was simply that the settlers were not trained to cope with the serious problems raised by the climate and the soil. Since the Forest Service was the only organized body of forestry experts who could furnish the needed professional skill, it was necessary to give this governmental agency a dominant role in the proposed project, with power to use their knowledge. There was never, of course, any question of compelling a farmer to allow shelterbelts to be planted on his land; he was free to refuse, and many farmers and landlords did so.

A second unusual feature of the project was that it was undertaken as a work-relief measure. The plains and prairies had been as hard hit by depression as the rest of the country, and the man power of those regions needed work as much as the soil needed protection. Here was a way, it seemed, in which thousands could be put to work doing something useful for their own localities. By the end of 1938 the project had used more than 65,000 man-months of relief labour, and it continued to provide this kind of employment, although in smaller and smaller amounts, until the books of the WPA were finally closed.

This feature of the project, like all the other "made-work" programmes of the period, provoked criticism. But the most serious controversy was raised by the third feature that made the Shelterbelt Project unlike any tree planting ever attempted before. This was simply its staggering size. For this was to be an attempt at wind control and soil protection over a strip of land 100 miles wide and stretching from the Canadian border southward over 1,000 miles. The original scheme called for the planting, within this strip, of approximately 1,800,000 acres. Although Americans were accustomed to thinking in large dimensions, this kind of thing seemed to many people fantastic.

Not only the size, but the very shape of these proposed plantings may well account for much of the distrust and the hostility. According to the first plans sketched out and given publicity, shelterbelts 115 feet wide, planted in parallel lines one mile apart, were to extend north and south across both the Dakotas, Nebraska, Kansas, Oklahoma, and deep into Texas. These rigid designs were abandoned, once the project got under way, in favour of a variety of sizes and shapes for the belts; for once trained foresters were on the ground, they saw that almost every farm presented individual problems of topography, soil conditions, kinds of crops, and climate, and that it was far better to determine the width, direction, extent, and composition of each planting on the basis of individual needs. But the mental image of block-wide files of trees deployed at one-mile intervals and marching with the unswerving doggedness of a German army across a thousand miles of the country stuck in the public mind. To many Americans it seemed a very symbol of the regimentation they had always hated and resisted, and the whole programme was bitterly condemned from many quarters.

Nevertheless, the order was signed and a million dollars was allocated to start it off, and despite the objections the project was soon launched. In those first years the Forest Service, recognizing the absolute necessity of continuing care for the young trees for several years after planting, tried to assure its own perpetual stewardship of the shelterbelts by obtaining from individual landlords easements or leases on the parcel of each man's land that was to be planted to trees. In 1936 this practice was abandoned in favour of a simple co-operative agreement.

Doubts and objections grew faster than the young trees that were being set out, and when the people's representatives convened in the Seventy-fourth Congress, the project that had been started by executive order was stopped by legislative action. Overnight the spectacular Great Plains Shelterbelt Project became a thing of the past.

Strangely enough, however, the work of planting trees and shrubs went right ahead, fully authorized by law and with WPA funds at that. Early in 1937 the Congress passed the Co-operative Farm Forestry Act. With the familiar give-and-take of American political life, the need of the plains and prairies for all the wind protection they could get was reconciled with the protests over "government control"; the lessons that had been learned by the Forest Service were incorporated into newly drawn plans, the acreage to be planted within the strip was scaled down, and the whole thing was taken out of the spotlight. Under the new law the Forest Service changed the name of its endeavour to the Prairie States Forestry Project and went quietly ahead with its work.

The new co-operative agreement worked much better than the original leases and easements. It provided that the individual landlord, if he wished to have shelterbelts on his land, would furnish the land, prepare it for planting, cultivate the plantation once it was set out, and share with the government in measures to protect it against rodents and insects. The Forest Service, on its part, was to do the actual planting, furnishing the necessary planting stock which it had grown in leased nurseries. A curious provision was that the shelterbelts were to be fenced, the landlord furnishing the material and the Forest Service doing the work. These fences are a detail not mentioned in descriptions of tree-planting projects in other countries, and seem to be an American innovation. They might serve a purpose in keeping stray animals out of the newly planted strips, but it looks as if the law may have provided for them primarily because the Prairie States Forestry Project, like its predecessor, was still operated entirely with WPA funds.

During the almost eight years in which the Forest Service worked on the twice-named project, it planted a total of 220,000,000 trees. The shelterbelts were in no set geometric pattern, but were designed to fit the needs of the particular farm and the wishes of its owner. Most of them were along property lines, and most were fairly short, although occasionally several owners would want to use a continuous boundary and the result would appear to be a single belt as long as two miles. The average belt had about ten rows of trees, although many had only four or five; here and there the local situation required only a narrow single row, while elsewhere the necessary belt might widen out to include twenty rows or even more. The total area covered by these plantations was 238,000 acres, in contrast to the 1,800,000 proposed in the original scheme.

It is important to notice that the Forest Service planted only field shelterbelts, because these were considered to have some value to the whole community, as well as to the family on whose lands they stood, and that only these are included in the above figures. Windbreaks, whose usefulness would be limited to the individual farmstead, were not made part of the public service. Nevertheless, the Project gave such great stimulation to the whole idea of wind control that thousands of farmers in the great strip took the occasion to improve their farms by planting windbreaks themselves, and today there are a great many more wind barriers on our plains and prairies than are accounted for in any official statistics.

The influence of the Prairie States Forestry Project has indeed spread far beyond the confines of the thousand-mile strip in which it was carried out, especially since 1942, when the Project was officially closed and the work of the Forest Service was transferred to the Soil Conservation Service of the Department of Agriculture. This latter agency had itself been encouraging plantings for wind control since 1934, and by 1949 it was able to announce that in its various soil-conservation districts scattered all over the country a total of 8,363 miles of protective strips had been planted. Shelterbelt planting has spread to the West Coast, where California fruit growers have planted 2,000 miles to protect their vineyards and citrus orchards. There are a hundred miles of sturdy trees on muck land in Indiana, protecting a host of truck farms and gardens. In fact, the work of taming the wind is still going on steadily all over the country. When the Soil Conservation Service took over, it found that there were on the books of the defunct Prairie States Forestry Project more applications for plantings than could be handled, because farmers in the area had become increasingly aware of their advantages. In fact, the Service has found farmers in various parts of the country asking eagerly for the establishment of new soil-conservation districts in their own localities purely on the basis of what they had heard about the Project.

By this time the original plantings have become sufficiently established for their permanent value to be assessed. Increases in livestock weight have been proved, and among other incidental advantages are such items as reductions of from 20 to 30 per cent. in fuel consumption when houses are protected by trees and shrubs. A number of the species that have been planted have commercial worth in themselves, quite apart from their usefulness as wind barriers, and many a farm family in the Great Plains region has found its income increased by the fruits, berries, and nuts gathered in a shelterbelt, by the increasing number of edible wild birds that have been attracted to the farm, and by the sale of small timber judiciously cut. A singular value of the Project to the country as a whole was that thousands of people who worked at planting and caring for the young trees, under the watchful eyes of the Forest Service, got some fine professional training, and the techniques and skills they acquired will continue to be used for many a long day.

The greatest values, of course, are in the increased yields that can be expected from properly protected field crops. In the fabulous corn belt the highest yields of America's greatest crop are coming consistently from tree-protected fields, where the shelterbelts have proved their ability to prevent the "firing," or yellowing of the leaves caused by hot winds, which is the chief menace to corn. Cotton farmers in Oklahoma and Texas get considerably more bales of fibre from fields that are protected. In Arizona and California individual growers of citrus fruits have found that eucalyptus belts can cut their cullage losses (the inferior fruit that is culled out from the marketable harvest) from the usual 50 per cent down to as low as 19 per cent. And not only do they get a higher percentage of good fruit, but there is a higher yield altogether. One interesting reason for this increased yield from protected orchards is that bees will not work in wind; on the leeward side of a good wind barrier, they do a much better job of pollination, with the result that more fruit is formed.

But it is not merely by reducing wind velocities and temperatures that shelterbelts aid the farmer to produce larger crops. Equally important in a dry country is the fact that trees conserve moisture. This is especially noticeable in regions where much of the annual precipitation comes in the form of snow; in the tree belts the snow piles up into drifts five, or even ten feet deep, and the slow melting of these drifts soaks the moisture into the ground. The fields themselves retain added moisture, since much less snow is blown away. It is true that the tree roots use up a good bit of the water themselves, and that in the rows closest to the belt the field crops are apt to be dried and stunted. But this loss in a couple of rows is more than compensated by the increased moisture, and hence the increased yield, of the rest of the field.

Because the worth of properly planted shelterbelts and windbreaks is now thoroughly understood by agricultural scientists, their use is spreading in many countries. In some, where there has been some previous experience with them, new and greatly expanded projects are under way. In others trees and shrubs are being planted for the first time by people who are just beginning to realize that it is possible to exercise some control over the wind and to reduce the damage it does. One of the larger projects to be reported recently is said to be going forward in northern China. The New York *Times* reported in June of 1951 a broadcast dispatch from the Tass Agency which described a large-scale attempt to lessen the effects of dry, hot winds blowing off the Gobi Desert. According to the report, Chinese peasants and mutual-assistance groups had planted 200,000,000 saplings in the spring of 1951, and had made plans for setting out an equal number during the remainder of that year.

The most ambitious of contemporary tree-planting projects, and indeed the most considerable single attempt yet made to protect agriculture in this way, is the one now being carried forward in the very area where so much pioneer work was done in the nineteenth century, the steppe country of European Russia. For despite the work done in the past in that country, wind and drought still create a very serious problem.

Above the deserts of Central Asia, the air rises dry and hot. Lifted by the prevailing easterly winds over the Ural foothills straggling down toward the Aral Sea, this parched air sweeps westward, flooding out over the steppes, across the Volga, and on west to the wheat fields of the Ukraine. Wherever it goes, the leaves shrivel, the soil is dried and powdered into dust, the wind picks up the dust and scatters it far and wide; drought and famine take over, and erosion eats at the precious layer of topsoil. For generations this has been the problem Russian tree planters have been trying to solve. In the lower Volga region, for example, there have been twenty-two severe droughts in the last sixty years.

Earlier wind-control efforts in the region have been rewarding, but they have been too small to break the pattern of drought and crop loss because of the immensity of the exposed area. The land that is affected by these hot winds out of Asia covers approximately three hundred million acres, extending from the Ural Mountains to the Danube. Its northern limit is a wavy line running near the cities of Ufa, Kazan, Moscow, and Kiev; on the south it is bounded by the Black Sea, the Caspian, and the mountains of the Caucasus.

So far as the climate and ecological conditions are concerned, this wind-swept portion of Russia is quite comparable with the northern part of the Great Plains of America, which includes not only the upper part of the strip where we carried out our project, but all of Nebraska, Minnesota, and the two Dakotas, as well as the cultivable parts of Montana, Wyoming, and Colorado lying east of the Rocky Mountains. But to the Russian people and to their national economy it is vastly more important than the northern plains are to us.

Population densities offer one striking index to the difference: on the average, a square mile of our northern plains region is occupied by only nine people; in the comparable area in southern Russia, the population averages sixty-seven to the square mile. Furthermore, this population produces out of the steppes 60 per cent of all the grain and the industrial and oil-bearing crops that are raised in the entire Soviet Union. Whereas we have other regions in our country more favourable for grain production than the northern plains, the windy, drought-menaced portion of Russia is the best natural grain-producing region in all that vast Union of Soviet Socialist Republics. It is the richest land they have, and yet in the past, despite all they have done to protect it, they have not been able to count on more than two normal harvests in every three years.

In October of 1948 the Soviet government announced a fifteen-year plan of work, the object of which is to control the wind and to remove for ever, if possible, the threat of devastating drought from these vital three hundred million acres. It goes beyond this, for in its entirety it is really a scheme for remaking the agriculture of the region, and it involves much more than tree planting. But since this particular part of the project is the most comprehensive programme of its kind ever undertaken, and since it is an attempt to see what protective afforestation can do when it is applied over the whole of a wind-exposed region, it will be watched with the keenest interest by all who are concerned to know just how much can be accomplished, what problems will develop, whether there will be any general effect on the climate, and a hundred other matters.

Statistics set forth in the announced plan are really staggering. Throughout the whole region, a total of 15,200,000 acres is to be planted to protective belts of trees and shrubs. Thus about 5 per cent of the land is to be withheld from cultivation in order to protect the remaining 95 per cent. Of course much of this acreage is not at present cultivated anyhow, since many of the plantings will be made on eroded land, in gullies and ravines, around the edges of rivers and lakes, and on shifting sands.

The great bulk of this forested acreage (14,900,000 acres) is to be occupied by the same kind of windbreaks and shelterbelts already described. No rigid scheme has been drawn to make them all alike: their individual size and orientation are to be determined by the needs of the particular locality, as was done in America. The Russian foresters have apparently not forgotten their earlier devotion to massed plantings, however, for 300,000 acres are to be occupied by wind barriers which seem to represent a kind of cross between a forest area and a shelterbelt, and which the Russians are calling "national forest belts." These will be fairly wide strips of trees extending for hundreds of miles across the region, generally in a north-south direction, more or less at right angles to the prevailing winds. Four of these national forest belts will be planted along both banks of the four major rivers of the region: the Ural, the Volga, the Don, and the Donets. Of the others, one will follow roughly the watershed between the Ural and Volga, from Kuibyshev southward to a point well below Stalingrad; another, starting along the west bank of the Volga above Stalingrad, will proceed south across the Caucasian steppe to Cherkessk; still another will start at Penza, some 150 miles west of the upper Volga, and swing south and south-west across the Don to terminate at Kamensk on the Donets. The announced purpose of these forest belts is to increase the usefulness of the field shelterbelts by acting as major barriers against the wind, and also by protecting the principal watersheds, conserving moisture, and preventing erosion of the river banks.

Characteristically, the Russians plan down to the last detail, and they have announced specific figures on the amount of planting that will be required to fill this enormous acreage with trees and shrubs. In all, they will have to prepare and plant 34,000 million pieces of planting stock. Responsibility for the work is to be divided between government agencies and local farms. The Ministry of Forestry will be responsible for planting nearly four million acres, the Ministry of State Farms for approximately one and a half million acres, and the collective farms for the remainder.

In order to try to assure careful planting and continued attention to the young seedlings, the government has adopted a bonus system that recalls the early state tree bounties in the United States. In addition to the regular pay for the initial work, the members of the collective farms are to receive a further sum if 80 per cent or more of their trees and shrubs survive the first year. The amount of this extra payment is to be figured according to the size of the particular planting; for each hectare (approximately two and a half acres) the collective will receive as a bonus the wages ordinarily paid to one man for ten days' work. If more than 85 per cent of the seedlings survive the first year, the bonus will be fifteen labour-days per hectare. At the ends of the second and third years, the plantings are to be checked again, and if 80 per cent or more of the trees and shrubs are still surviving, the collective will receive further bonuses of eight labour-days per hectare. Since all this will add up to a tidy sum for the successful planters, the government is apparently trying to provide as strong incentives as it can for conscientious work.

The very magnitude of the Russian plan has caused some observers to dismiss it as a pipe dream, just as many critics declared that America's Great Plains Shelterbelt Project, in its original proportions, was a total impossibility. Certainly the proposal to plant 34,000 million trees and shrubs in fifteen years (six million every single day, with no time out for holidays) sounds like a tall order. It is possible that as they settle down to the work these original plans may be quietly scaled down. Russians, like Americans, have a tendency to bite off more than they can chew, and they may possibly whittle down their new plan to more manageable proportions, as we did our Great Plains Project. But whether or not they persevere until the last tree is in the ground, there can be no doubt that they are embarked on a programme which they consider vital and that they are making a very serious attempt to reduce the danger of wind and drought on their best land. For in addition to this afforestation programme, they have mapped out a great many other protective measures.

Although most authorities agree that the establishment of barriers is essential to any successful wind-control project, it is generally regarded as only the first step of a number that must be taken if one's object is to get dependable high yields on dry and wind-swept land. This is doubtless why the direction of American tree planting was eventually given to the Soil Conservation Service, which could make it a part of a well-rounded, co-ordinated attack on the total problem. For it is not wind alone, but the combination of wind, drought, and loose dirt that causes dust storms, erosion, and crop failures. All these enemies have to be fought together, and with a variety of weapons.

Droughts cannot be prevented, for a drought is simply a lack of rainfall, and at present men know no practical way of increasing natural precipitation significantly over a large area. But since the important thing is not the amount of water that falls, but the amount that seeps into the ground and is stored up for the use of plants, there are a number of measures that can be taken to prevent the destructive effects of drought. Tree belts are only one factor. Another is irrigation, and the Volga Irrigation and Hydro-electric Plan, announced in 1950, is obviously intended to supplement the afforestation programme in southern Russia, just as similar projects have done in many parts of our country.

But perhaps the most basic thing is the condition of the soil itself. To most city dwellers earth is earth, and they are not aware of the enormous variations among the topsoils of the world unless some catastrophe of nature brings it forcibly to their attention. I remember the disgust of a taxi driver in a town on the High Plains of Texas when a shift in the wind showed him something of this diversity. For over a week, during that winter when the Dust Bowl blew out from under our feet, the air had been filled with red, gritty sand. Then one morning there was a difference. The whole atmosphere was a thick and murky grey, and soft black grime was filtering down upon us. "I don't like it," fumed the taxi driver. "I don't mind honest-to-God Texas sand, but this here's Kansas dirt, and I don't like it."

Agricultural scientists have known for a long time that the term "soil" covers as wide a range of different things as "vegetable" or "animal," and they have spent a great deal of energy in increasing our knowledge of the manifold variations in this thin layer of earth on which our life depends. Scientists of the U.S. Department of Agriculture have even constructed elaborate wind tunnels in which they can test the "blowability" of different soils. And from all this study has come the knowledge they now use to change the very composition of a given soil, to improve its quality and make it less susceptible to destruction by natural forces and hence more serviceable to man.

Poor soil suffers most from both wind and drought, and the measures that are taken to improve the condition of soils work always to lessen the damaging effects of both these natural forces. Loose dirt dries out, and it also blows and washes easily. On the other hand, soil that keeps its original structure and is bound together with organic matter not only retains more moisture, but it also stays on the ground under a high wind. Knowledge of such facts has led to the development of a great many methods of soil improvement.

These methods include, among other things, the use of various crop-rotation systems. Most of them involve the planting of deeply rooted grasses, because these improve the water permeability of the soil. Ploughing, sowing, and tilling on the contours is a favourite method of preventing run-off and increasing the amount of water that gets down into the earth. A whole series of field practices are designed to keep down weeds and maintain a mulchlike condition on the surface; usually this means adding organic matter (crop waste, straw, manure, and the like) to the soil in order to make it more porous and also more resistant to wind. Since the greatest loss of moisture occurs through evaporation from the top rather than from seepage down into the subsoil, anything that cuts down this form of drying out on the surface is beneficial. Tree belts, mulches, temporary ground covers, and scientific methods of cultivation all help.

Many of these measures are incorporated into the overall plan of agricultural improvement which the Russians are now proposing to apply to their three hundred million windy acres. It would appear that insufficient wind barriers have not been the only cause of the uncertain yields of the past, but that throughout the whole region the general practice of agriculture has remained backward by American standards. To judge from the measures that are proposed as "new," farmers on the collectives and state farms still have much to learn about such matters as autumn ploughing, disking of stubble, application of both organic and mineral fertilizers, and the selection of certified seed in terms of local requirements.

One very important item in the fifteen-year programme is the provision that crop rotation is to be introduced on all the fields. Those that are now given over to the same crop year after year are to be planted about two years in five to perennial grasses and legumes. On meadows and pastures these soil-building covers will be planted about five years in seven. Similar rotations are the backbone of good soil-conservation programmes in many other countries. In southern Russia it will involve a radical change in the agricultural economy. It means, in effect, that the region will have to become a major livestock-raising area, as well as remaining the "breadbasket of Russia," in order to consume all the extra hay and fodder that will be grown. One minor provision of the plan calls for the construction of some 45,000 ponds and reservoirs. These will not only be used to water the stock, but it is hoped that they will do their bit for soil improvement by reducing run-off erosion and increasing the moisture in the surrounding fields.

The ultimate purpose of all this activity is simply to introduce, if possible, an improved and much more stable agriculture. What the Russians are after is a larger annual yield from their land and the ability to count on it in bad years as well as good. There seems no doubt that in making their plans to try to accomplish this, they have drawn heavily on the experience of many other countries, but the example they are always citing as an evidence that such results can be obtained is one in the very region they are now proposing to improve.

A good many years ago one of their greatest agricultural scientists, Dokuchayev, started an experimental farm in the steppe country, on which he tried to test the value of shelterbelts, ponds, crop rotations, and other methods that are incorporated in the new plan. His work was carried further by a Russian scientist with the Welsh name of Williams, whose special study was soils. It was Williams who took issue with most of the authorities of his day by announcing the theory that soil, instead of inevitably losing its fertility over long periods of cultivation, could actually be improved and made increasingly fertile if it were properly used. At the Dokuchayev Scientific Research Institute, the farm where the theories of these men and others, both Russian and non-Russian, have been most thoroughly tested for their applicability to steppe conditions, yields of grain have been doubled, and in years of severe drought those fields have produced three to four times as many bushels as were reaped on the surrounding farms. It is the so-called "travopolye" system of agriculture employed at this farm, a term that embraces the co-ordinated use of all these methods of soil conservation and land management, which the Russians now hope to establish over all that part of their country that is at present scourged by the hot winds out of Asia.

Since the Russian plan covers an entire geographic unit, the whole extent of a wind-threatened area, there has been a good deal of speculation about its possible effect on the climate. The Russians consistently talk about "changing the climate," and suggest that their work, if successful, may actually induce changes in the rainfall, temperature, and other climatic factors. American scientists, studying the effects of their forestry project, have been able to observe no such changes in the over-all climate of the plains and prairies. The geographer Professor George B. Cressey, in a conference held at the Russian Research Centre at Harvard to discuss the Soviet programme, has stated his considered judgment that although man-made factors can produce slight modifications in local conditions (a forest cover lowers soil temperature a little, for example) ". . . man cannot change the basic factors of climate nor can he alter its many cycles."

It would seem, however, that any hope of "changing the climate" is somewhat beside the point. The purpose of all such projects is not really this; it is to change the *effect* of an adverse climate on man's productive efforts. When men plant tree belts and undertake general soil-conservation work, they are not trying to make the wind stop blowing or to force clouds to bring more rain. They are simply trying to cope with the elements as best they can, preventing as much damage as possible and getting the fullest use from the resources they have, all for the purpose of harvesting as much food from the earth as their labour can produce. If the Russians succeed in doing this, they will have accomplished enough.

The worth of their effort has been obscured for many people by one of the irritating habits of Soviet publicists. Instead of merely announcing their plans, and letting us applaud their courage in attempting such a big job in fifteen years, they have alienated many observers by their repeated assertions that "only under Socialism and only in the U.S.S.R. can such projects be carried out." This is the kind of thing that makes people's dander rise, especially when they remember their own successful undertakings.

But our natural annoyance at such ideological boasting should not blind us to the significance of this plan, nor to the consequences it can have. If, in a land that is already a major food-producing area, crop yields can be stabilized at a rate even partly as high as is hoped for, it will be a major contribution to the solution of the world's food problem. Even if the whole thing should fail, its very failure would have much to teach us. After the passions aroused by ideological controversy have died down, agricultural experts will long continue to study this largest of contemporary efforts to control and reduce to impotence one of the great enemies of the land.

Putting the wind to work

AT THE SAME time that agricultural scientists in many parts of the world have been developing methods of preventing wind damage, other scientists have been trying to devise ways of harnessing this great natural force and using it for production. The idea is not a new one. Centuries ago men conceived sails to capture the wind and make it propel boats and ships, and even a few vehicles that travel on land or on ice. Very ancient also is the small windmill for grinding grain, pumping water, and performing other tasks on a relatively small scale.

But as the need for large amounts of power has increased with industrialization, men have been giving more and more attention to the problem of making much greater use of this energy which sweeps in wasted floods around our planet. Everyone is agreed that it represents a vast resource, if only we could harness it. Conservative estimates put the usable fraction of wind power at something around two hundred times the water power we are now using.

In order to put this potential power to work, however, we have to solve several rather tricky problems, the chief one of which is that there are very few places in the world where the flow of wind is constant. At many points wind reaches extremely high velocities, so that with efficient wind turbines we can generate enormous amounts of electricity. But sooner or later the wind dies down for a time, and the generators must stand idle until it begins to blow again. Since we have not yet learned any way of storing large amounts of electricity, these periodic failures of the power have operated to prevent any large-scale use of wind for heating, lighting, and industrial production. The solution, of course, is to build wind-power plants in conjunction with supplemental installations using conventional fuels, and switch over to these when the wind fails, and this plan is being followed in the few large-scale projects that are now under consideration.

The great advantage of wind power, even when it must be combined with some other supplemental source, is that once the cost of the installation has been paid, it is virtually free. Wind as a "fuel" costs nothing, whereas coal and oil become increasingly expensive. The experiments of Palmer Cosslett Putnam at Lincoln Ridge in Vermont have proved that wind power, supplemented by power from other sources, can compete economically with the cheapest of our other resources in supplying electricity for large urban centres. More importantly, all the technical problems of constructing and servicing a 1,250-kilowatt wind turbine have been solved; a standard design is ready for mass production.

It seems certain that in the near future men will make increasing use of the power latent in the wind. Small wind-power plants are becoming more common all the time; in the arctic regions they are rapidly replacing the plants that use expensive imported fuels, and there are few polar stations that do not depend almost completely on the wind for their light and heat. Whether we shall see large-scale installations at various places in the world may be decided by our success or failure to use such other possible sources of power as atomic energy, solar energy, and tidal power; for it is certain that men will have to find some sources to supplement falling water and expensive fuels. The interesting suggestion has been made that sooner or later the antarctic continent, with its almost continuous gales, may become the powerhouse of the world, but since it is 600 miles from the nearest land, there seems not much likelihood of this happening unless it becomes possible to transmit great currents of electricity by wireless.

In the meantime, what practical results can the development of wind power have on the basic problem of food production? Apart from the fact that power, from whatever source, can be used to do a lot of necessary work about a farm, one immediate possibility seems highly desirable. It has been suggested that in the colder agricultural regions, which are usually windy, electricity generated by groups of windmills could be sent into wires laid permanently underground, where it would warm the soil. We know that in electrically heated soil we can produce earlier crops; more significantly, we can get two or three crops a year instead of one. Wind failure would not matter, for the soil would hold the heat long enough to prevent freezing before the current began to flow again. There seems to be no technical obstacle to making such a use of wind, and the cost of the undertaking would be paid back in the increased yields.

Such proposals are admittedly speculative, at the present stage of human affairs. What is not a matter of speculation is that human beings can control one of the most irresponsible of all natural forces. A great deal of the damage wind does to fields and orchards and pastured flocks can be prevented, and at least some of its destructive force can be bridled and put to work.

IX. BATTLE AGAINST DISEASE

THE COMBINED ASSAULT of plant, animal, and human diseases is one of the major reasons why we do not have enough food to go around. The enemies that attack the land itself are fearsome, but they are outmatched in destructiveness by the host of ailments which afflict all that lives on the land. And yet there is now such a wealth of the scientific and technical skill needed to fight them down that many diseases could be stamped out completely, and many others brought under control. If it were put to use, man could make, without any new acreage at all, an impressive start along the road to abundance.

Perhaps one reason why he has not already arrived there is that, so far as most diseases are concerned, he has only recently had any clear understanding of what they were. Their effects have been observed from time immemorial, but for thousands of centuries no real headway was made against them because no one had the foggiest notion of their cause. Scientists were feebly fighting in the dark against something they had never seen and could not conceive.

Up until the late seventeenth century when Leeuwenhoek first looked into the world of microscopic life, human beings went along blissfully unaware that we share this planet with uncountable billions of minute creatures, all as eager to survive as we are. Their discovery created a sensation, but although it was recognized as a landmark in the history of man's exploration of his homeland, micro-organisms remained for nearly two more centuries a mere curiosity of the laboratory. The realization that some of these fragile "animalculae," as Leeuwenhoek called them, carried in their delicate and beautifully intricate structures the seeds of death dawned as recently as ninety years ago, within the lifetime of many people now living. Since that time a great many microscopic organisms have been positively identified as killers whose primary objective seems to be the annihilation of mankind and of all living things on which he feeds.

Once the real villains were identified, scientists began to take effective measures against them. From the disease makers that could be seen under a microscope, they proceeded to some so small that no instrument can make them directly visible. They were successfully combating several of the non-filterable viruses long before the electron microscope gave photographs of them. To destroy them before they destroy us or our food, modern researchers have developed a whole arsenal of different weapons.

Plant diseases have been particularly troublesome, because a sick plant is a very difficult thing to treat medically. Some can be treated for certain diseases, and frequently cured, by the application of chemicals. Much study is going forward with the relatively new antibiotics, which have already been so effective in controlling various human and animal diseases, and a few promising results have been published. Streptomycin, for example, although so far it has had no helpful effect on tomatoes already suffering from bacterial speck or canker, has controlled these diseases when it was used on infected seeds before planting. The growth-stimulating hormones are also being tried, and pathologists at the University of California, for example, have found one of them effective in checking the virus of tobacco mosaic. Study of these two new methods of treatment is only beginning; some day they may be perfected and widely used.

In the meantime, however, the most effective way to fight plant diseases is not to treat infected plants but to give healthy plants immunity. Animals and human beings can generally be protected in this way by vaccination and inoculation, and once the offending organism is isolated, they are fairly easy procedures. But you can't inoculate a stalk of wheat, to say nothing of a field containing millions of stalks. You can, however, build up immunity in another way.

Most of the food-producing plants exist in a great number of varieties, all with slightly different properties and characteristics. Among these are varying degrees of resistance, or even outright immunity, to the diseases that attack the particular species, just as there are individual people who are born immune to smallpox or typhoid fever, and who carry that immunity like a charm all their lives. Whenever a particular disease threatens one of our staple crops, botanists all over the world undertake a search for varieties that have the natural ability to fight it off. Once such a variety is found, the geneticists begin an elaborate series of cross-breedings, in the attempt to produce a strain that has all the desirable qualities of delicate cultivated varieties plus the disease resistance of some tough old member of the family which has never developed "the finer things of life."

Sometimes the search for resistant varieties takes a very long time, and involves many people in widely separated lands. For example, growers of sweet potatoes in the United States were frustrated for years by a disease called "wilt," or "stem rot." It is caused by a fungus that clogs up the water-conducting tissues of the plant, so that the potato simply dies of thirst. Stem rot is a killer, and once it gets into a field, there is not much a farmer can do about it. In 1917 it destroyed nearly two million bushels of sweet potatoes in the United States, and it frequently has taken half the crop in certain sections.

Nobody could help the farmers, however, because all the known varieties of sweet potatoes were about equally susceptible to the disease. They went right on losing a large part of the crop every year until a soldier's boredom produced the long-sought plant.

Lt. Sidney Du Bose had been a student of horticulture at the Louisiana State University. When the Second World War came, he got into the Air Forces, and eventually found himself on the island of Tinian, a tiny speck on the map of the Pacific. Like many men in the army, Du Bose kept up a lively interest in his peacetime work, and to relieve the tedium of his island assignment he began in his spare time to explore the plant life of Tinian. Among other things, he found some sweet potatoes that looked particularly healthy. He sent three strains back to Louisiana, and from there they were sent on to the testing station of the U.S. Department of Agriculture at Beltsville, Maryland. And there government researchers found that one of the three had a higher resistance to stem rot than any variety yet tested. Even when it was planted in soil deliberately loaded with the deadly fungus, it came through. It is not very good to eat, but this does not matter. All that American farmers want of it is its resistance, and it is only a question of time until this factor is bred into the fine edible varieties.

One can be very positive about the ultimate success of such crossbreeding; once the Tinian variety is found and its resistance to stem rot established, we know that sooner or later we shall have a sweet potato that combines all the eating qualities of the best strains with this single factor derived from the Pacific-island plant. The reason for the confidence is that from this point onward in the process of hybridization the geneticists will be doing exactly what they have already done successfully with hundreds of other plants. Wheat rust, which was once a much graver threat to human welfare than sweet potato stem rot, has almost disappeared from the North American continent, because the farmers plant hybrid varieties that are immune to it. Those hybrids were produced by crossing formerly susceptible wheat with rust-resistant varieties from northern Europe. The same story can be told of scores of food plants. In fact, the processes are so well established that you cannot look through the most ordinary catalogue of garden-vegetable stock without finding in almost every species at least one developed variety with strong resistance to the common diseases that attack it.

In addition to hybridization, there is another method of getting disease resistance in cultivated, high-yielding plants. It is being used to produce the rubber trees that will be planted in the Huallaga Valley of Peru, and is of particular interest because of the important bearing this work at Tingo Maria may have on the development of the Hylean Amazon generally.

Until the First World War, the Amazon Valley was the world's primary source of natural rubber. The latex was harvested from wild trees, and the production was never very great, but it was enough to supply human needs before the advent of the automobile and the aeroplane. In the latter part of the nineteenth century, however, trees from Brazil had been transplanted to the East Indies, and under intensive cultivation the East Indian plantations have now developed to the point where they are virtually the only source of supply. Because they do not produce enough, chemists have been forced to make one of their greatest achievements, the synthesis of rubber. Yet the world still needs more natural rubber, and the hope is that Amazonia may supply it.

The first Brazilian trees to arrive in the Indies were wild things, and did no more work for man than they had to, producing only about 350 pounds of raw rubber per acre. But scientists went to work on them, changing them as they have changed so many thousands of natural objects, and today some plantings are yielding as much as two thousand pounds per acre. It is evident that if Amazonia is to compete with the East Indies for the rubber market, the yield of the native trees must be increased correspondingly. This cannot be accomplished by merely transplanting East Indian trees back to the home of their ancestors, because those trees, during seventy years of easy-going life in the plantations, have lost all their native resistance to a number of diseases that lie in wait for rubber trees in the Amazon Valley, especially the deadly South American leaf blight. But by an interesting series of grafts, horticulturists are solving the problem.

First, they select a seedling from the native wild Amazon stock, one that is particularly tough and has the kind of roots that can pull the most life out of the Amazon soil. Then they cut it off, and bud-graft on to the stump a branch from one of the high-yielding East Indian trees. If they stopped there, they would have a potentially good rubber producer with a strong base, for it is the main trunk of the tree that yields the latex. But they would probably never get much rubber from it because when it grew up it would sicken and die. When the little double tree begins to grow well, the scientists again cut off the top. This time they graft on to the East Indian trunk a branch from another native Amazon tree, one that has never produced much rubber, but that has built up an immunity to nearly all the diseases that might attack it.

The result is a three-in-one tree. Its roots and base are tough stay-at-homes, that know exactly how to establish themselves in their native soil. Its trunk is a delicate and highly cultivated traveller, that has learned how to produce the maximum. Its top is another native that can stave off diseases and produce healthy seeds.

Using both hybridization and grafting, science has already established definitely that plants can be protected against disease. Even so, there is still much work ahead for the plant breeders and the horticulturists. Despite all that has already been done, harvests all over the world are still reduced drastically by diseases. For some of them growers already have good resistant varieties, but they are known only in the countries where they have been developed; the task is to spread their cultivation to other areas, as we Americans are now exporting our magnificent hybrid corn. For certain others, such as potato blight, resistant varieties have been found, but the long labour of crossbreeding them with good edible varieties remains to be done.

But the big job for botanists in the near future is to continue the search for varieties that are immune to those diseases against which we have at present no defence. From the few preliminary surveys that have been made, it is reasonable to conclude that somewhere in the world there exist plants that could confer immunity against any disease we know. But ignorance of the botanical riches of this planet is greater than present knowledge, for the world still contains a plenitude of uncatalogued plants. Botanists have still a long search ahead before they find strong varieties that can protect all the common food crops.

The conquest of plant disease must be a major objective of science in the future if we are to feed our rapidly growing population. It is no more important, however, than the measures we shall have to take against the diseases that afflict our domestic animals and poultry. These are legion, and the economic toll they take is enough to make the stoutest optimist blench. Yet as recently as the last two decades such a dreadful scourge as bovine tuberculosis has been virtually eradicated from the United States, Denmark, and several other countries. More significantly, and even more recently, scientists have discovered means of wiping out even more devastating plagues.

There is good reason to hope that in this one department of our economy, at any rate, men may actually use the skills that are now available, because the economic toll of animal disease is something everybody can understand. From the time when animals were first domesticated, men in general seem to have regarded meat-and-milk-producing herds as one of the most precious of possessions. Most early cultures at some period or other made cattle or oxen the legal medium of exchange. The idea that they represented the only true wealth remained so strong, in fact, that when the Greeks invented coins they stamped the picture of an ox on the metal to show that it was good money.

People are still well aware of the value of herds. Mothers know that milk is the one food their babies cannot do without. On millions of Asian farms the single water buffalo is the very staff of life for a human family, without whose strength the fields could not be ploughed, nor the transport of products and supplies managed at all. To the Bedouin his camel is almost the sum of his wealth, as are the Laplander's reindeer and the sheep or goats or cattle of other peoples. Without domesticated animals even the highest civilizations could not survive. That is one reason why the Nazis, in their sweep into European Russia, either stole or wantonly slaughtered seventeen million head of cattle, and why they did the same with horses and oxen all over Europe.

Yet disease takes a heavier toll of the world's herds, over the years, than even such destructive agents as the Nazis.

Before the war it was estimated to cause a loss of two hundred million gallons of milk every year in England and Wales alone. Mastitis, a disease of the udders, still takes away a pint of milk apiece, every day, from fifty million European children. Sleeping sickness prevents Africa from outproducing Argentina; and throughout the world, at least three million cattle die of rinderpest every year.

Such facts are extremely discouraging until one realizes that they are no longer inevitable. For centuries men have been helpless to combat them, but within the decade of the 1940's weapons have been developed with which all these major diseases can be completely overcome. The cure for mastitis, for example, is penicillin. In America we have no trouble with the disease any more, but it will remain a curse to some of our less fortunate neighbours until the money to increase penicillin production is forthcoming. Actually, the sums needed are not large by American standards; they are just not available where they are needed. The Food and Agriculture Organization has been trying to help with the mastitis problem in Europe, but it cannot afford the necessary expense. Mastitis control is only one small project it must try to carry on out of literally hundreds of undertakings all over the world, in every department of food production and supply. Since for its entire work this organization must operate for a full year on $5,000,000—a smaller sum than the cost of one long-range bomber—it may be some time before European children get their full supply of milk.

Mastitis is a serious threat to world supplies, but it is a relatively minor ailment when compared with such a disease as sleeping sickness. That malady is one of several borne by the tsetse fly, an insect which for many years has been absolute ruler over a constantly expanding area in Africa, now twice the size of the United States. Wherever the tsetse fly has gone—and its dominions have been growing at the rate of a thousand square miles annually—it has carried the microscopic blood parasites called trypanosomes. When, through the bite of the fly, these organisms enter the blood stream of a healthy animal, the victim is condemned to slow, stupefying death. This has been the fate of millions of men and of their domestic animals; the economic result has been the uninhabitability of much of the best land in Africa, and the consequent undernourishment and poverty of whole populations. The diseases carried by the tsetse fly have been a major obstacle, in fact, to the development of agriculture in that rich continent.

During recent years, as men have become more and more alarmed by the spread of this death-carrying insect, all sorts of efforts have been made to stop it. None has succeeded; the fly has continued to multiply, driving men and animals before it in headlong flight. Unable to fight off the insect, health officials have tried to combat the diseases it carries, and have had fair success in protecting people against the deadly sting and in treating the human form of sleeping sickness. But until 1948 they had found no way of protecting the animals upon whose health the well-being of men depended.

In that year chemists in a British factory made a discovery which may do more for Africa, and for the world, than the combined effort of all the explorers and developers, from Stanley and Rhodes on down. Like so many of the important advances of modern science, this discovery was the result, not of one man's experiments and deductions, but of the co-ordinated work of a whole group. Some twenty-five people—chemists, research workers, biologists, pharmacists, and veterinarians—working together in the Manchester laboratories of Imperial Chemical Industries, shared the labour and the credit. There were two men, however, who were chiefly responsible for the final achievement: the biologist Dr. D. G. Davey, and a brilliant chemist, Dr. H. F. S. Curd, whose death in the Stockport train crash a few months after the discovery was one of the tragic losses to British science.

Three years before the discovery of a weapon that may conquer the tsetse fly, Drs. Davey and Curd had been two members of a three-man team who discovered "Paludrine," a coal-tar derivative compound which is very useful in treating malaria. This success naturally led them on to investigate other similar compounds derived from the same source. Like most work of this kind, it was largely a matter of making hundreds of more or less routine tests, without any very clear idea of what they were looking for, in the hope that somewhere along the line some unknown property in one of the compounds might be revealed. For quite a while nothing significant happened. Then one day a compound was injected into some mice that were suffering from diseases borne by the tsetse fly, and the sharp eyes of the laboratory worker detected a slight improvement in their condition.

At once the machinery of scientific inquiry went into action, to determine whether the compound had produced that slight improvement, and if it had, what caused it to do so. Exhaustive tests finally established that it was nothing in the compound itself that had produced the effect, but an impurity that had somehow got into it. When this impurity was finally located, Dr. Curd and his fellow chemists had in their hands for the first time the key that could open tropical Africa. It is a white crystalline powder which has been named "antrycide."

Once the laboratory men had produced a sizeable quantity of the new chemical, Dr. Davey and the veterinarians took over, and began a long series of experiments that have resulted in establishing antrycide's extraordinary value. They proved first that in its pure form it is a sovereign remedy against sleeping sickness in animals. But its properties are even more remarkable than this. Not only is antrycide a certain cure for the disease; injected under the skin of healthy animals, it provides complete immunity against any disease borne by the tsetse fly for periods varying from four to seven months. It is completely harmless, producing none of the troublesome "side effects" of many other drugs. And it is perfectly simple to handle, so that untrained farmers can easily give the necessary injections themselves.

In other words, African farmers can now hope, not only to save the emaciated animals that are already infected, but with two or three routine injections each year to free their herds for ever from the tyranny of the fly. They may still have to put up with the insect as a barnyard nuisance, but its terror will be gone.

The conquest of sleeping sickness that is now possible does not, of course, guarantee Africa's future. It does indeed give humanity the opportunity to use millions of acres of new grazing land, rich pastures that could support more than Argentina's thirty-three million cattle, and some twenty-five million sheep besides. But it does not give the sanction to misuse them, as men have misused so much fine land in the past. Some experts say that the tsetse fly, by keeping out destructive mankind, has actually preserved the most fertile half of tropical Africa, protecting it against the erosion and soil exhaustion men themselves have created in the other half. Of course, one may ask, "Protecting it for what?" but this is no answer to the challenge. If antrycide is to make its potentially great contribution to the increase of our food supply, men will have to use the new land it gives just as sensibly as they must use the rest of our agricultural heritage.

There is also the human element, and the ticklish problem of human relations which a new instrument of production is apt to create. When the British writer Ritchie Calder was discussing the great possibilities in antrycide with a group of the Hausa people in Africa, one dark-skinned man arose and said seriously, "My people say, 'The tsetse fly is our soldier. It keeps out the white man.' " Here is food for some serious thought on the part of those who would develop Africa, not only about the effect of their work on the land but about the people who will make that land increasingly productive.

The great scientific advances do not confer on man any licence to do as he pleases. He has sometimes taken the licence, but he has always paid bitterly for his stupidity and greed sooner or later. Anyone who imagines that the extraordinary opportunities science has now presented to the human race are opportunities to indulge the cupidity, the savage cunning, the self-seeking that have characterized some of our earlier activity is preparing himself for a most uncomfortable disillusionment. It is one of the laws of life, apparently, that from more highly developed species nature demands a greater sense of responsibility; the more intelligent creature must act more intelligently or perish, the better equipped must use his equipment to further the processes of life or he will be rewarded with death. So it will be with us in our use of antrycide and the lands it can give us.

There is another recent discovery even more remarkable, in some ways, than this drug that cures and prevents sleeping sickness in animals. Since the Second World War, we have had available for the first time in history an effective weapon against the most deadly of *all* the diseases that attack our herds. It is so devastating that when the Germanic peoples first encountered it they called it simply "rinderpest," which means *the* cattle plague, the worst, the one and only.

When Attila and his Huns swept into Europe, rinderpest was one of the terrors they brought with them. They did not use it consciously as an instrument of war, probably because at that time it had not occurred to anybody that it might be so used. But their own cattle had the disease, and from them it spread to the herds of all the conquered peoples, creating more damage in the long run than the Huns themselves.

Ever since that time, rinderpest has been associated with war. Every barbarian invasion of Europe brought a fresh outbreak of the plague. Later on, when the Europeans themselves set out on their own conquests, they took rinderpest along with them to Africa and the Middle East. Fortunately, it has never reached either North or South America, but it has spread so widely elsewhere that it is a major cause of famine and poverty generally. In China, for example, it kills at least a million cows and water buffaloes every year. Since the average distribution of these animals in China is one for every two farm families, the annual death rate means not only the loss of milk for two million families; worse still, it means that the land on all those stricken farms must be cultivated entirely by hand until a healthy animal can be bought, with resulting fractional yields and increasing poverty. Clearly, the world stands in need of some effective weapon against this dreadful plague.

When the United States and Canada entered the Second World War, scientists and livestock men were quick to realize that one of the most staggering blows the Nazis could inflict on us would be to infect our herds with rinderpest. Even the barbarians did not dream of the conscious barbarism of biological warfare, but we knew that the Nazis had dreamed of it. Rinderpest can kill up to 90 per cent of a herd in a few weeks, and it is so highly contagious that it could sweep like a prairie fire from one end of the country to the other.

And we had at that time no real defence. One effective vaccine was known, but since it had to be manufactured in the bodies of healthy calves, and the calves then had to be killed in order to get it, it was extremely costly. Furthermore, the preparation of this vaccine in any quantity is a slow and cumbersome process. When the scientists who were charged with protecting the herds figured it up, they found that to furnish this "tissue vaccine," as it is called, for the sixty million head of cattle in the two countries they would have to work day and night for over sixty years.

In order to combat rinderpest, if the Nazis should use it as a weapon, we clearly needed a less expensive vaccine which could be produced quickly and in quantity. To find such a vaccine was the problem set for a group of Canadian and American scientists appointed by the Joint U.S.-Canadian Commission and the Chemical Warfare Service of the

U.S. Army. The group was headed by Dr. Richard E. Shope of Princeton, who was at that time serving with the Medical Corps of the U.S. Navy, and it included six officers from the Veterinary Corps of the Army, two Canadian officer-scientists, and a corps of technicians from both countries. Because rinderpest is so contagious, the group did not dare handle the virus in any of the laboratories where such explorations are usually made. Instead, they set up their equipment on Grosse Ile in the St. Lawrence River, where they could hope to isolate their experimental animals from any contact with other cattle.

They began work early in 1942, trying first to produce an adequate stock of virulent rinderpest virus and then to convert this virus into a safe vaccine. They started with a small quantity of the Kabete strain of the virus which Dr. R. Daubney of the Egyptian Ministry of Agriculture had developed in the bodies of goats several years earlier. The group at Grosse Ile used eggs as the medium for multiplying the virus. In their first report, Commander Shope, Capt. Dubois L. Jenkins of the U.S. Army, and Capt. Henry J. Griffiths of the Canadian Army tell how they succeeded in maintaining the virus for the necessary number of passages in eggs. Because the supply of electricity at their hastily constructed laboratories was very uncertain at first, they noticed that the temperature in their incubators kept fluctuating more or less rhythmically between 32° C. and 38° C. Since they managed four serial passages under this fluctuating temperature, they at first thought that perhaps such changes of heat were necessary to their success, but when the power plant was finally fixed up and they got a steady current, they found that this was only one of the "freaks" that are constantly misleading good scientists: the virus multiplied better under a constant temperature.

Once they had a sufficient stock of virus, they began attempting to weaken it, again by passages through the embryo of a chick. By July, 1944, Commander Shope and Capt. Jenkins were able to report not only that they had succeeded in producing a safe vaccine, but that "the attenuated virus solidly immunizes calves against virulent bovine spleen virus. This immunity is effective within ten days." Here was at last a defence against a possible Nazi attack. Since eggs are far more plentiful than calves, and far less costly, this new "avianized" vaccine can be produced at a fraction of the cost of tissue vaccine, and large quantities can be obtained in a short time. Later experiments have confirmed that it does give complete immunity, with little or no reaction.

Fortunately, we in the United States and Canada have never had to use it. But today the Food and Agriculture Organization is doing all it can to make the vaccine available in those countries where it is desperately needed. Before the Communist revolution in China, members of this agency had helped the South-east Epizootic Bureau to develop its laboratory at Hsiao Hong in Nanking, where Chinese technicians quickly made two outstanding contributions. In the first place, they did much to further the development of a lapinized vaccine, that is, one which is manufactured in the bodies of rabbits. Of more immediate concern, however, was their success in attacking rinderpest with the avianized vaccine. In 1949 they announced that they had already cleared the disease from two provinces, and that they hoped by the end of that year to eradicate it from all of China south of the Yangtze River. Since the Nationalist government was a member of FAO and the Communist régime is not, the foreign experts withdrew from Nanking after the occupation. There are no reliable reports on what has been done about rinderpest since that time, although the Chinese staff that remained in the laboratory was by that time perfectly able to complete its work alone.

The FAO team was transferred to a place near Bangkok in Thailand, where they set up a vaccine-production laboratory, using strains of "seed" virus from China. It is hoped that this laboratory will eventually supply the needs of all of South-East Asia. Meanwhile, FAO has sent strains of virus and advisory assistance to Burma, India, Indo-China, Pakistan,[*] and Egypt. When an outbreak of rinderpest threatened the lives of 300,000 water buffaloes and cattle on Formosa in 1949, a veterinarian from the United Nations agency went immediately to the island to help the local authorities, taking with him a supply of virus for use in making vaccine. But this is not the end of the rinderpest story. In fact, when one considers the situation in Ethiopia, it seems only the beginning.

Ethiopia has one of the most curious livestock problems in the world. Its cattle suffer fearfully from the ravages of rinderpest, as do those in nearby Anglo-Egyptian Sudan, Somaliland, and some other African countries. Yet despite the serious annual reduction of their herds, the Ethiopians produce more meat than they can consume. They would like, naturally, to export the surplus; but no one will buy it, because of the deadly fear that rinderpest might come with it.

Widespread use of the new vaccines, plus some modern packing-house equipment, could make Ethiopia one of the great meat-producing countries of the world. It could provide an economic base on which a high modern civilization could be built. And of course such a development would have a vital effect on our world-wide struggle to produce more food for our growing population. Between them, antrycide and the new rinderpest vaccines, if used wisely, can enable us to make of Africa what earlier generations made of the New World, a larder from which the older and more crowded countries can draw large amounts of food in return for industrial products.

What is at present hampering Ethiopia is simply the lack of funds and materials to establish laboratories, to build packing plants, and most of all, to train Ethiopian personnel in the techniques of rinderpest control and meat processing. The much-overworked FAO has made a start in that country, but the money it could spare for the enterprise was insufficient to carry it beyond the initial stages.

All over the world this is the kind of frustration against which our best scientists are beating their heads. In every department of human activity, modern man has painfully acquired the knowledge and the technical skill with which he could easily make a world in which three thousand million people or more could live in dignity and comfort. His tragedy is that he has not yet been able to persuade himself to do it.

He says, of course, that he cannot afford it. Yet the sums required for such measures as effective control of animal diseases are trifling compared with what he squanders on some of his more colourful enterprises. Furthermore just as water-control projects are self-liquidating, which means that in the final analysis they cost nothing, so disease-control projects always pay back far more than their cost. Norway has recently eradicated brucellosis from all but nine of her 2,758 herds; it took twelve years, but the total cost of the campaign was less than the amount Norwegians had lost *annually* as a direct result of the disease. Before the Second World War, a single epidemic of foot-and-mouth disease cost Germany more than a billion gold marks, and there were corresponding losses in neighbouring countries. Such losses still occur in other parts of the world. Yet from Denmark's famous Lindholm laboratories, where a successful vaccine was developed in 1938, it is possible to obtain protection for threatened herds at a cost of less than a dollar a head. Since we now have the means of controlling the major animal diseases, it would seem that humanity has the opportunity for some highly profitable investments of public funds.

The same kind of opportunity awaits us in the field of human medicine. The health and strength of the farmer, after all, is as essential to full production as the health of his land or his crops or his animals. In the great cycle of production, human labour is really the most important single element. When it is diminished, all the other elements suffer and yields decline. That is why the elimination of certain debilitating diseases would be a most potent factor in increasing the amount of food available for human consumption.

There are of course a multitude of diseases that prey on human beings, weakening our powers and making us unable to produce what we could if we were healthy. Against some of them we are still helpless, and the time when mankind can protect himself completely against all the "thousand natural shocks that flesh is heir to" seems very far in the future indeed. But there are several diseases, which medical men know perfectly well how to combat, that are still needlessly draining away the strength of our man power and thus cutting wide swathes in our food supply.

One of these is malaria, a malady that has in the past destroyed great civilizations and that today keeps millions of farmers inactive. Sometimes malaria kills its human victims; more often it simply reduces them to a state of suspended animation. Mr. Barrett Shelton, the energetic publisher of the Decatur (Alabama) *Daily*, gave a vivid description of it when he spoke at the United Nations' great conference on conservation in 1949. "Did you ever have malaria?" he asked, and his question seemed to be directed personally to each of the delegates, the specialists who had come from all over the world and from every department of human activity to confer about the world's dilemma. Since both he and many of his fellow townsmen had suffered from the disease, he went ahead to prod that distinguished company of scientists by thrusting before them the seldom-heard voice of the patient.

"Do you know what you want to do when you have malaria? Nothing. You want to prop your feet on your desk, or if you are not an office man, perhaps you'll take a day or two off from your job in industry or take out of the fields, just to get a rest. Malaria is restful—and non-productive."

Then Mr. Shelton went ahead to explain to the experts, again from the point of view of the citizen whose community has long been oppressed by malaria, just what their work of eradication means when it is done well, as it had been done in his own Tennessee Valley. "Soon after the creation of TVA, a nationally-known manufacturer of full-fashioned hosiery bought a bankrupt hosiery plant in our community. The new company introduced physical examinations for all employees and found that 35 per cent had malaria. Ten years later, after the TVA malaria-control programme had been in action, the figure dropped below 1 per cent. Today, because malaria is completely controlled, this hosiery firm does not even require the malaria test in physical examinations. And what happened to the people in that plant? Why, they out-produce the employees of three other plants of the same company."

There, in the experience of one small community, is the whole story of malaria: its personal and social damage, the comparative ease with which it can be conquered, and the resultant upsurge in the release of creative human energy. The last point is particularly worth pondering. One sometimes hears irresponsible people characterize the inhabitants of a whole district or even a nation as "lazy" or "shiftless," and go on to generalizations about how futile it is to try to help them improve their lot. In these days when the whole fate of civilization seems to hinge on whether the under-developed peoples are brought into the framework of modern industrial society as equal and active participants and sharers, people with such prejudices would do well to consider malaria.

It has been brought under control in the Tennessee Valley, but there are still many less fortunate places where it is a centuries-old plague. The mosquitoes which carry it have become absolute lords over large areas of rich and fertile land, just as the tsetse fly has driven humanity out of its dominions in Africa. The Terai region in India, for example, belongs almost exclusively to the mosquito. The land is rich, and ought to support a large population, but every attempt to settle it in the past has been defeated. In eastern Pakistan there is a slightly different problem: a great rice-growing area, very densely populated, in which no one can make a good living. But the reason for the poverty is not poor land or even actual overcrowding; it is malaria, which has weakened the people to the point where they cannot work. If they could be protected against the disease, they could produce from their land enough rice to feed themselves and have some left over for export.

For a long time it was thought that little or nothing could be done about malaria in such places. Recent experiences in Italy and Greece, however, show what modern methods of control can achieve, not only in a richly endowed country like the United States where the malaria damage is only a minor factor in the national economy, but in countries with much graver problems and with nothing like the resources for handling them. In 1945 there were 470,000 cases of malaria in Italy; four years later, very few people on the Italian mainland had the disease, and not a single one died from it in a twelve-month period. Spraying of the mosquito-breeding grounds with DDT had made the entire peninsula reasonably safe for the first time in two thousand years.

In Greece, before the Public Health Division of the ECA mission started its attack on the mosquitoes, the situation was far worse than it had been in Italy: two million people —more than a fourth of the entire population of Greece— were ill with malaria. In 1950 the incidence of the disease had dropped to 50,000; and the Greek people, by buying DDT to kill mosquitoes instead of the much more expensive quinine to cure malaria, were saving a million dollars annually. Even the cost of the DDT is much more than offset by the gains in farm production. In some areas yields have already increased nearly 40 per cent as a direct result of the conquest of malaria.

Observing the success of such anti-malaria campaigns, India and Pakistan have started programmes for rescuing their stricken regions. They are being advised and helped by experts from both of the United Nations agencies concerned: the FAO and the World Health Organization. The latter agency has already made some highly significant tests on selected fields in East Bengal, as a preliminary to an all-out campaign. They have found that two-year sprayings have resulted in a 15 per cent increase in agricultural output, and because healthy farmers can work better and faster, these increases have been made with a saving of at least 10 per cent in man-hours of labour per acre. Since mosquitoes can easily travel from an unsprayed farm to a protected one it is evident that when the whole countryside is treated these figures will be considerably higher. While the work in East Bengal continues, the United Nations agencies are at the same time attempting to expand their malaria-control work into many other countries. For example, a large project is under way in Haiti, and so far the results have been very gratifying.

Some such international action is sorely needed against many other diseases. Wherever poverty is the lot of a large farming population, human disease of one sort or another is rampant, weakening the people, cutting down on their productiveness, and thus deepening the mire of their poverty, in a vicious circle of ever-increasing misery from which there seems no escape. Middle Eastern countries have the highest blindness rate in the world, largely because the people do not have the simplest and cheapest protection against the flies that carry trachoma. Bilharzia, the dreaded worm of the Nile, cripples as many as 75 per cent of the fellahin on thousands of Egyptian farms. Since the parasite enters the body through the bare feet, as the fellah sloshes through the irrigated fields, it has been said that the provision of a pair of rubber hip boots for every farm worker would wipe out this horrible, wasting disease. So far landowners have not thought it profitable to supply the boots, and so long as Egypt is desperately overpopulated and the labour of a man is the cheapest of all commodities, there is little likelihood that they will. Yet healthy fellahin, freed from the scourge of bilharziasis, could make the land produce more than it does. If this were accompanied by the sorely needed reforms in land tenure, rising standards of living would create further increases in production.

No one denies that the problem of human disease is related to the even more serious problem of food shortage in the face of increasing population. The theory is often advanced, however, either despairingly or cynically, that prevention and cure of disease only intensifies the shortage. If there is a real danger that within fifty years we may find ourselves starving, the argument runs, why deliberately aggravate the situation by helping to push the survival rate of humanity still higher? To the people who hold such views, a human being saved from death is simply another mouth to be fed, another body to be clothed and sheltered, another person to be taken care of.

This, of course, is the Malthusian fallacy. It regards the human being solely as a consumer, and forgets all about the fact that he is first and foremost a producer. When he is ill, naturally, he consumes more than he can produce, but this only means that if we want him to cease being a drain on the economy we had better speedily restore his health if it is humanly possible to do so. Masses of disease-stricken men and women do undoubtedly constitute a serious threat to the supply of food for the whole community. But masses of healthy people are, in the final analysis, one of the most potent instruments we could develop for increasing that supply to abundance.

X. WASTE NOT, WANT NOT

EVEN MORE DESTRUCTIVE than disease is the sheer waste through which, every year, millions of tons of human food are lost to human consumption. It is no exaggeration to say that if we could eliminate waste completely we should have more food than we need, even if all the other measures for increasing our supplies were neglected.

To a woman scraping into the garbage can a few uneaten morsels from her family's dishes, and thinking this is what is meant by "waste," such a statement is preposterous. If that were all the term means, it would be. It is true that the extravagance practised in most American kitchens, and especially in our restaurants, is disgraceful, and fills our more frugal neighbours with justified horror. But the edible food that goes into the garbage cans of the world is a rather negligible fraction of the real waste we ought to be concerned about. When we speak of waste, what is significant is the appalling amount of potentially good food that never arrives in the kitchen, but is destroyed or thrown away before human beings get a chance to eat it. Much is eaten by other living creatures before men can harvest it, and much again after it has been gathered and put in storage. Mountains of potential food are deliberately thrown away because nobody knows how to make the food substances in them palatable. And finally, tons upon tons are wasted through what we shall have to admit is just plain senseless folly.

When you begin to investigate these losses, you get a quite different picture from the one the lady at the garbage can had in her mind. Consider, for instance, what damage insects account for. Every year, according to the U.S. Department of Agriculture, they eat up more than 10 per cent of American food crops before farmers can harvest them. These farmers are better equipped to fight back than the people of most countries; losses in the rest of the world are almost certainly higher. Now what does this mean in terms of feeding the growing human population? Since something over two thousand million human beings are managing to exist on what is salvaged at present, it means that insects are consuming in the field enough to keep alive at least two hundred million extra people, or *ten times* the number annually added to the world population.

Obviously, if men seriously want to increase the amount of food available for human consumption, they ought to be throwing everything they have against these insect marauders. Up to a point, at least, they are trying to do so, and successes in the past indicate that farmers can hope to retrieve more of their rightful yields in the future. In 1929 fruit growers in Florida beat off an invasion of the Mediterranean fruit fly, which would have destroyed their whole industry if it had become established. American wheat farmers knocked out the Hessian fly in the early 1940's; they did it by the ruinously expensive method of burning the standing grain in their fields, but they have not been troubled with this particular pest since. In Africa a large international campaign has just about brought the locust under control, and as the breeding grounds from which this insatiable insect invades other parts of the world are discovered, we can expect further declines in the toll it takes.

Many other insects, of course, are still happily gorging themselves on crops men have planted for their own nourishment. In 1949 our Bureau of Entomology in the Department of Agriculture made a serious attempt to combat grasshoppers, using aeroplanes to scatter poisoned bait, and managed to save about fifty-five dollars' worth of food for every dollar spent in the campaign; but even so, the grasshoppers still got away with food valued at over $27,000,000. We are at last making some headway against the European corn borer, which costs us more than twelve times that figure. The green bug aphid threatens to be a more serious destroyer of wheat than the Hessian fly was; and all over the cotton country the boll weevil continues "looking for a home," and to assist him in this laudable endeavour we have paid as much as half a thousand million dollars in a single year.

These four are generally regarded as the most dangerous of the six hundred insect species our Department of Agriculture considers major pests in this country. They are aided and abetted in their struggle against humanity by the beetles, the nematodes, the weevils, the fruit flies, and the bewildering variety of aphids and bugs and worms whose existence is a constant threat to our own.

The single example of cotton offers an instructive glimpse of the size and variety of our insect enemies. Americans tend to think of the boll weevil as its only pest, since that is the principal one they have to contend with. But in the fields of the world entomologists have already identified no fewer than 1,330 different insects that attack cotton plants.

We may as well admit that the complete elimination of all the six hundred species that trouble American farmers, and of any of their foreign relatives who may at some time or another invade our shores, is something we cannot hope to achieve. Some of the loss we now suffer is inevitable, and try as we may, we shall always have to hand over a portion of our food to insects we would be much better off without. One reason is that although we know ways of killing many of them, we cannot employ our most effective weapons on the necessary scale because there is too much chance of killing other things in addition to the pests.

Among the 800,000 known insect species in this country, the vast majority are neither helpful nor harmful to man, so far as we know; they are merely fellow inhabitants of the planet, toward whom we have no reason to wish anything but length of days. Quite a number, however, are of very substantial value to mankind, and we had better pay the annual grasshopper tribute than risk losing their services. We could, I suppose, spread enough poison in the air and on our fields to kill every insect in the country, but if in such a general slaughter we destroyed our pollinating bees, we should lose far more food than we would save.

A second very real danger in too heavy use of poisons is that we might damage the food plants we were trying to protect. Careless use of insecticides can have equally serious effects in other directions. California fish and game wardens believe that the periodic death of thousands of trout, steelhead, and salmon, which they have long observed, is caused by rotenone sprays washed into the streams from the backs of cattle. Many disquieting reports have indicated that such poisons as DDT may even affect the health of human beings.

We may be sure that in the future a great deal of work will be done toward finding safer and surer insecticides, which can be used with greater controls. In addition, entomologists are devoting more research to other weapons. They are already carrying on bacteriological warfare against some insects, when they have found a disease that is death to a particular pest and quite harmless to any other form of life. They have had some success in this connection in spreading "milky disease" among Japanese beetles.

Parasites are being used in a similar way, when the entomologist can be sure he has one that will attach itself to no living thing except the particular insect he wants to destroy. In Barbados, where the sugar-cane borer formerly infested as much as two-fifths of the crop, an egg parasite (Trichogramma) has been introduced. It has so effectively reduced the borer population that now, in a normal season, no more than one-twentieth of the cane crop is attacked.

A similar method of attack is being used on the European corn borer, which is one of the four most serious insect enemies of American production. For thirty years entomologists of the Department of Agriculture have been seeking means to combat this pest, and it now looks as if they have found an effective one. During the growing seasons of 1950 and 1951, from 40 to 60 per cent of the borer population was killed by the maggots of the Lydella fly, an insect that looks very like a common housefly. The female Lydella has the habit of depositing her offspring, in maggot form, at the entrance of the tunnel some borer has made in a cornstalk. The hungry little creatures crawl up the tunnel and when they find the borer they simply eat out its insides. They have effectively put an end to billions of borers in the corn belt already, and it begins to look as if this particular destroyer may go the way of the Mediterranean fruit fly.

Normally entomologists work to find ways of destroying insects because the insects are eating up valuable plants. There are occasions, however, where the roles are reversed:

a plant becomes a nuisance, and the entomologists then deliberately foster some insect that will destroy it. Some fifty years ago, for example, a weed called St.-John's-wort emigrated from Europe and established itself in the range country of California, where it is called Klamath weed. In recent years it has spread over thousands of acres, killing out the range grass and producing a peculiar ailment in the cattle that eat it. Klamath weed has the strange property of making the animal's skin allergic to sunshine; the photosensitized skin breaks out in blisters and sores, and the animal loses weight and presently dies. When the usual methods of weed eradication failed to stop the spread of Klamath weed, the rangers appealed to science.

In Australia a beetle was found which would eat nothing but this particular weed. When a few specimens were promptly imported, however, they refused to lay any eggs. Although they ate their monotonous diet greedily, they left no offspring to continue their work, and the colony soon died out. Entomologists eventually found the reason. The beetles were not native to Australia; they had been imported there from the south of France, and in order to survive in the Southern Hemisphere, they had had to change their life cycle completely to fit in with the reversed order of the seasons. Brought back once again into the Northern Hemisphere, the beetles refused to make such a radical adjustment again. They had learned in Australia to lie dormant during the long winter rainy season and to emerge for their egg laying after the rains were over. Lacking the accustomed rainy season, they simply refused to reproduce themselves.

The solution to this odd little problem was really inspired in its simplicity. The men in charge of the insects imported some in the dormant state, and after their arrival in California sprayed them with cold water every day. When the beetles awoke, thinking they had lived through a rainy Australian winter, they began happily reproducing their kind. Their offspring are now making a sizeable dent in the patches of Klamath weed, and it appears that they will eventually remove the troublesome pest entirely.

There is still, of course, much to be done in the war against the insects that destroy our food crops. But so much headway has been made in recent years in all the departments of pest control that entomologists today believe the picture is far from hopeless. Some go so far as to say that it is even technically possible to eliminate all the destroyers without hurting other forms of life. It would cost billions, but when one considers what it costs to kill several million human beings in a modern war, to say nothing of what the food wars of the future will cost unless we remove their cause, it may not appear a bad investment.

There is another group of pests against which we will find it much easier to contend. These are the insects, rats, and other predators who invade, not our fields, but the granaries in which we store the food we have been able to harvest. Losses in storage do not amount to anything like those in the field, but they are still sizeable enough to warrant serious concern. The Food and Agriculture Organization, studying what happens to the rice and bread grains of the world while they are waiting to be prepared for human consumption, produced some figures that ought to open our eyes. Rats, insects, and fungi destroy annually some 33,000,000 tons of these essential foods. That is enough to feed the entire population of the United States for a full year. Applied another way, the figure means that if one person out of every fourteen or fifteen in the world should die yearly from starvation because of a real lack of food to go around, we could say quite literally that he was done to death by these predators.

Some of the losses in storage occur because we do not know any way to prevent them, and one of the principal objectives of the professional entomologist is to discover workable methods. Millers have long been troubled by grain weevils, for example, because their presence could not be detected until it was too late to do anything about them.

These insects have a cunning way of burying their eggs inside the individual grain and sealing the hole so that it cannot be seen. Farmers could sell and mills could buy infested grain in complete innocence.

We were helpless to do anything about this situation until an American government entomologist, Mr. J. C. Frankenfeld, found a quick and simple way of detecting the hidden eggs. He takes sample grains from a bin and soaks them for a few minutes in a dye that contains acid fuchsin. When the grains are washed, every place where there is a hidden weevil egg shows up as a bright, cherry-red dot. Of course this little trick of Frankenfeld's is purely a method of detection, and does not by itself destroy any weevils. But it very effectively prevents the sale of infested grain, and this, in turn, will certainly lead to improved methods of storage and greater care.

Although this kind of discovery is a small item in the whole colossal problem, thousands of such little advances in human knowledge will finally enable us to stop the great waste of food in storage. Continued research is so important that the Department of Agriculture in 1951 set up an entire new division to study the control of insects that destroy stored products. And yet, even more important today than the discovery of new knowledge is the sharing and spreading of knowledge we already have. Scientific progress is not always measured in terms of the totally new. If science has any meaning, that meaning is in the use human beings make of it. And there are millions of people in the world today who are using only the tiniest fraction of humanity's collective knowledge. For them, and for all of us, some of the great scientific advances of our present era have nothing to do with the latest news from the laboratories.

There is an interesting story from Egypt that illustrates the point. Early in 1948 the Egyptian government, concerned over serious losses of grain in storage, asked for an expert from the Food and Agriculture Organization to come and give them his advice. That organization's Plant Industry

Branch promptly sent Mr. Stephen S. Easter, an entomologist with long experience in FAO, the U.S. Army, and the Department of Agriculture. When he arrived, the Egyptians took him out to see how they stored their grain. Most of it was kept in what are called "shounas," that is, open places on the bare ground, surrounded by a wire fence and a drainage ditch. They simply put the grain into jute bags and piled it up in the shouna.

But to show their visitor how careful they were, and how hard they were trying to save their grain, they pointed to numbers of women down on their hands and knees on the ground around the shouna. Those poor women were patiently taking up handfuls of dirt and shaking it through sieves; once in a while one of them would proudly rise up and present two or three grains she had found, and these would be solemnly put into a jute bag.

The pathos of the whole scene was underlined when Mr. Easter looked at the shouna itself. There he could actually see rats running in and out, and insects crawling over the bags. Overhead was a cloud of birds, also waiting for a meal.

FAO, as it turned out, had picked a very clever man. He criticized nothing. He only looked, and finally he asked a question: How much did the jute bags cost? It seemed that they were not bought, but rented for two or three piastres a month, that is, about 15 cents apiece. He asked how many bags were in each shouna and they told him. After some quick figuring in his head, the American finally made a suggestion. If they took the money they would spend in bag rental over a period of only seventeen months, they could build a concrete storage house that would be ratproof, insectproof, and birdproof. There they could store the grain in bulk. Concrete would last about fifty years, during which time they would not only protect their grain against the pests but would also not be out a penny for renting bags.

This is the kind of thinking that can radically alter the food situation in many parts of the world. In all the less fortunate communities the need is not so much for more scientific penetration of unknown areas of thought as for widespread education in fundamentals. And just as in American towns the residents of wealthier neighbourhoods pay a larger proportionate share of the school taxes, so in the world community those people who need such education most seriously cannot be expected to support it entirely by themselves.

In the more advanced countries, with their elaborate technical equipment, a major weapon in eliminating waste must of course be specialized research. For it remains true that in spite of our vast knowledge we are still throwing away prodigious amounts of potential food because we do not know how to save it. Out of every seven eggs put into our commercial incubators in the United States, for example, only five hatch. One turns out to be infertile, and in one the embryo begins to form but dies before it becomes a fully developed chick. Both infertile and "unhatchable" eggs are perfectly good to eat when they are fresh, and if someone could devise a way of detecting them before they go into the incubator to be spoiled and wasted, Americans could save some six hundred million eggs every year, enough to fill a fully loaded freight train 21 miles long. On the other hand, if the causes of "unhatchability" in fertile eggs could be found and eliminated, we could have three hundred million more chickens every twelve months.

What are the chances that we may acquire the needed knowledge? All we can say is that successes in eliminating waste in many other directions would indicate that this egg problem, like many others that plague us, need not be dismissed as for ever insoluble. Only a few years ago it was taken for granted that when pears were canned a good bit of waste was unavoidable; when a housewife bought a can of this fruit she cheerfully paid not only for what was in it but for the skins, cores, and stems that were thrown away by the canning company. It was not much on a single can, but factories in the United States were throwing away a grand total of one hundred thousand tons of this material every year. Since neither human beings nor any of their domestic animals or poultry would eat it, there seemed nothing else to do. Finally, however, the men working at the Department of Agriculture's Western Regional Research Laboratory in Berkeley, California, found a use for the pear waste. They discovered that it makes an excellent medium for growing a certain kind of yeast, rich in proteins and vitamins, that is an important element in poultry feed. As a result, what was formerly wasted annually can now be used to produce half a million dollars' worth of concentrated feed.

Wheat straw is another material for which a practical use has recently been found. Fields in the United States produce about ninety-five million tons of this straw a year, and a good part of it has been salvaged for such desirable purposes as replenishing the soil on which it grew. But because there is more than can be used in this way, American farmers have been burning up about forty million tons after every harvest. The whole world produces nearly three billion tons annually, and how much of that total is wasted nobody knows.

The farmer naturally asks, "If I don't burn my surplus straw, what on earth can I do with it?" Scientists have known for a hundred years how to make fine paper and other pulp products from wheat straw. The trouble has been that it cost so much to collect, transport, and manufacture it that very few people could afford to buy the finished products. The paper industry and the Department of Agriculture have been working for several years on the collection and transportation problems, and have made some headway in persuading farmers that strawstacks are valuable. But the most powerful incentive to conservation is a method of converting the straw into pulp cheaply, developed by E. C. Lathrop and his associates at the Northern Regional Research Laboratory in Peoria, Illinois.

The old way was to cook the straw under 25 to 60 pounds pressure for anything from four to twelve hours. The new method cuts costs by eliminating the need for artificial pressure and by reducing the time to an hour. Since its introduction more effective chemicals have been found which give a larger quantity of pulp of still higher quality, and cut the time to half an hour. All this means that wheat straw can now be used economically in combination with wood pulp to produce fine paper products at reasonable prices. This may not seem particularly important until one reflects that, at the present time, whole nations are learning to read who never read before. If they are to be educated they must have a great deal more paper than they have had in the past. Since wheat straw can supply 40 per cent of the pulp in a good paper, it should be possible to stretch out somewhat the rapidly diminishing stock of wood pulp.

It is high time, indeed, that men found more ways of conserving wood, for at present it is one resource on which they have put intolerable drains. In the United States the annual cut of saw timber, plus losses from natural causes, is 50 per cent greater than the annual growth. Certain other countries are much nearer to timber starvation than that. In fact, if anyone wants to prove that humanity is nearing the end of its rope, one of the solidest facts he could advance in support of such a pessimistic view is the sad state of the forests.

Wood resources are most dangerously low, but again the cause for this situation is not an inability of nature to supply actual human needs. The U.S. Forest Service has put on record its considered opinion that there is in the world enough productive forest land to meet the requirements. The primary reason for the shortage is not genuine overconsumption but simply waste. In the United States forest fires, insects, diseases, and wind destroy annually four and a quarter billion board feet, or nearly a tenth as much as the amount cut. And when they have done their work, and the healthy trees that have escaped them are felled, the waste of our wood is only beginning.

It is true that in exploiting our timber resources we in the United States are among the "backward" nations, and that much of our loss is due to practices which Europeans would consider disgraceful. Nevertheless, the foolishness of humanity accounts in some other countries for even greater waste than we indulge in. A case in point is the crossties that are used in most Asian railroads. In the first place, the governments that own most of the railways are in the habit of commandeering not only the bulk of all the available timber to make these ties, but the very best, the cream of the crop. The fine Asian hardwoods are so much stronger than the woods used for this purpose in Europe, that in order to support the rails firmly the Asians need to use only a third or a half as many ties per mile. But they go right on following specifications that were worked out in Europe a hundred years ago, needlessly wasting a large part of their precious timber. Finally, their methods of processing entail the waste of nearly 50 per cent of each log that is converted into ties. If the railroad builders could be persuaded to draw up new specifications based on the actual quality of their local woods, and to adopt methods of conversion that would reduce their losses to the 10 per cent found in the best managed European mills, the timber famine that confronts such a country as India could probably be averted.

Just as with many food products, so it is with timber: a certain amount of waste seems unavoidable, but it is far less than we tolerate at present. It may be impossible to eliminate tree diseases and predators completely, but the amount of damage they do can certainly be reduced. The Forest Rangers have saved large percentages of our wood crop by protecting American forests against such enemies as the spruce budworm, the pine bark beetle, and the gypsy moth. It is also possible by crossbreeding to create hybrids that are resistant to disease, as is being proved in the long struggle to re-establish the chestnut that was driven from our country by blight, and in the still-unfinished battle against the Dutch elm disease.

Policing of forests has reduced the losses from man-made fires, but severe destruction still occurs as a result of lightning, which starts as many as three-fourths of all the fires that sweep American forests in a year's time. Although such fires are fought as hard as any others once they are started, very little has been done so far to prevent them. To most of us it would seem that there is little anyone could do to prevent lightning from striking a forest. However, Dr. Vincent Schaefer, a meteorologist who has done a great deal of pioneer work in scientific rain making, has put forward a bold proposal which may well lead to a significant reduction in our losses from such fires.

The only kind of cloud that produces much lightning is the cumulus, and it does so only when it boils up like an enormous mushroom into what is called a towering cumulus. When it is building up, such a cloud is a highly unstable affair, filled with rushing upcurrents of air and spitting out lightning in all directions. But before this happens, a cumulus is as harmless as any other cloud, and aeroplanes can safely fly through or over it. Dr. Schaefer's proposal, which grew out of his studies of the uncommonly large number of thunderstorms that afflict the region around the Priest River Forest Experiment Station in Idaho, is simply that the rangers attack the clouds before they reach the dangerous stage. As soon as cumulus clouds appear over a forested area, he suggests that men be sent up in aeroplanes to sprinkle them with dry ice. According to his experience, the clouds will either be precipitated in harmless rain or snow, or they will turn into thin cirrus clouds composed of snow or ice crystals. In either event, they will not build up into the towering cumulus that produces lightning.

Dr. Schaefer's proposal has not been thoroughly tested, but when one considers the amount of wood that is wastefully destroyed by lightning every year, it would certainly seem that it ought to be. The concept itself—the idea of forcing nature to refrain from creating lightning—is one that makes us understand something of what Sophocles meant when he wrote the great ode that begins, "The world is full of wonders, and the greatest of wonders is man." Unless we are willing to deny our nature and accept starvation, such bold thinking must inevitably replace some of the lackadaisical attitudes of the past. And indeed humanity is capable of it. All sorts of ideas for reducing waste have sounded completely audacious when they were first proposed, yet they have worked.

In earlier chapters of this book we have frequently noticed how characteristic of modern science and industry is the conversion of waste products into edible food. The same thing is going on in the wood industries. One might think there was no more unlikely source of food in the world than sawmill residues and the evil-smelling wastes from wood-pulp mills. Yet in 1950 Dr. Alfred J. Stamm, of the U.S. Forest Products Laboratory in Madison, Wisconsin, reported that pilot plants were already in operation, converting this material into digestible sugars, proteins, and fats. During the Second World War, the U.S. Forest Service developed a process by means of which a ton of wood waste can be turned into a ton of sugar-rich molasses. Although cattle will eat it, it is too bitter to please human palates; but the bitterness can be removed by filters or by crystallizing out pure dextrose sugar. Furthermore, it can be used as a medium for growing yeasts that compare favourably with baker's and brewer's yeast. Next to soyabean meal, yeast foods made from wood sugars appear to be the cheapest source of proteins yet discovered, with the possible exception of the algae scientists are just beginning to study.

From such examples as this it becomes clear that if men truly want to create an age of abundance, there is no natural or scientific reason why they cannot do so. It is highly unlikely that the human race can ever sit idle while its food appears by magic, but no sensible person has any desire to create that sort of world. What men strive for, and what "abundance" actually means, is simply enough food, clothes, shelter, and opportunity to work for everyone in the world. That is now a completely realizable goal, and one way we can hasten its attainment is to stop wasting.

The responsibility for reducing waste does not lie entirely with the scientists and the professional conservators, nor with the directors of industry and business, though all these have a part to play. It rests upon politicians and educators, civil servants and rampant individualists, upon rich men, poor men, beggar men, and all of us; a portion even comes back in the final reckoning to the lady at the garbage can. The world is faced with an acute shortage of tin, yet only under the stress of war can we in the United States, who eat more canned food than any other nation, be persuaded to salvage our tin cans. Scientists work desperately to discover ways of stretching world supplies of fuel, and nation glowers at nation across oil lands that belong to neither; yet the flares of natural gas burn pointlessly day and night in U.S. oilfields, consuming for no purpose whatever more energy than is generated by the entire series of TVA dams. Most American cities pay enormous sums to have their sewage destroyed; Milwaukee and some others receive a good income by selling it to companies that make from it one of the richest fertilizers known to modern science, and there is no sane reason why the rest of our communities should not do the same thing. While Frenchwomen beg the corner chemist for a bit of glycerine with which to make a little soap, the American housewife dumps into her garbage can the used cooking fat that is our principal source of glycerine, and no one asks her to save it unless he wants to make of it, not soap to keep people clean and comfortable, but explosives to blow them up. And the list of such follies could be extended almost indefinitely.

There are times, indeed, when human sanity seems to disintegrate under the pressure of forces it has created, and we treat ourselves to the abominable spectacle of food being deliberately destroyed while people starve for it. Photographs of mountains of perfectly good potatoes being systematically poisoned have appeared in our newspapers more than once. For such crimes against humanity we shall yet be called to account. Perhaps it is a vague sense of guilt that has prompted us to substitute a less obvious way of getting rid of what we fondly call surpluses. The method currently in fashion is not to destroy them publicly, but to store them up in every abandoned warehouse, cave, leaky ship, or worn-out boxcar we can find, there to lie quietly and unobserved until they rot.

Man can do much to reduce the waste that results from diseases and predators, and is doing a great deal. We can continue through scientific research to find more and more ways of converting what are at present waste products into edible food. But perhaps the greatest contribution we could make to human welfare would be to come to our economic senses.

XI. MAKERS OF ABUNDANCE

THE HUMAN SKILL that can produce two blades of grass instead of one has often been applied in the past, and today millions of farmers are getting far more food from their acres than their grandfathers got, and doing it with less effort. World yields are actually very high, by comparison with earlier periods, even though they are by no means high enough. But the evidence that they can still be enormously increased is conclusive.

We Americans like to imagine that our agriculture is the most productive in the world, and that because we enjoy the highest standard of living we must be getting the maximum from our land. Yet this is far from true. In western Europe farmers harvest about three times as much food per acre as we get here and in Canada. Even in eastern Asia, yields per acre are twice those in the English-speaking countries of North America.

This does not mean that Europe and Asia have any great natural advantage over North America as agricultural countries; it means simply that people in those areas do a better job of farming than we do, despite all our advantages in money, equipment, and technique. That we in this country could pull up our yields is amply demonstrated by the fact that for the last thirty years we have been doing so, at an average rate of about 1.5 per cent annually. Yet we are nowhere near to maximum production.

Furthermore, the possibilities of such increases in yield are not limited to the more highly developed countries. India's per-acre production is only half that of China, and one-fourth that of Japan, yet her land, on the whole, is better than that of either. In many underdeveloped countries pitifully small harvests are being gathered from highly fertile land. In such places the opportunities for raising the yields are even much greater than in the United States.

How are we to make our land give us more to eat? The methods of scientific farming are legion, and many have been mentioned in earlier chapters of this book. Anything that builds and enriches the soil makes for a better harvest; so do measures for controlling diseases and pests, and all the hundred-odd techniques of land management that are practised by skilled farmers. But there are three great divisions of agricultural science which must carry a large part of the burden of increasing world yields in the near future, and in each of them enormous strides have been made so recently that their effect is barely beginning to be felt. In trying to assess the equipment we have for producing an abundance of human food, we must take into account what is being done in the introduction of new crops, the use of fertilizers, and the breeding of improved high-yielding varieties of plants and animals.

Since some of the principal food plants of the world have been cultivated from time immemorial, their origins lost in the dim recesses of prehistory, many people tend to think of agriculture as a sort of "closed universe," in which all the elements sprang into being in some first creation and have persisted ever since. They therefore profess considerable scepticism when anyone suggests the possibility of "new" crops being introduced. And yet the history of agriculture is filled with such introductions. It is true that many standard food plants, such as maize, wheat, and rice, were established so anciently that we do not know when or where men first tamed their wild ancestors by cultivation and made them basic elements in human diet. But we know very well when the white potato became a staple in the economy of Europe, and the grapefruit in that of the United States.

All plants are weeds and wildings until man discovers in them some property that makes them worth the labour of cultivation. When the new-found property is sufficiently valuable to warrant large-scale cultivation, farmers have a new crop. This does not always happen immediately, as one can see from the history of New World plants that were introduced into Europe from the beginning of the sixteenth century onward. Tomatoes, for example, which now rank third among vegetable crops, were grown primarily as ornamental vines for several centuries, and most people thought the shiny red "love apples" were poisonous; only within the last hundred years have they been recognized as a valuable food. Similarly, potatoes did not become a new crop on European farms until fully two centuries after they were introduced; up to that time they were regarded as something of a curiosity and were thought to be fit only for making a sort of condiment which was eaten as a luxury.

The classic example of the "new crop" is the sugar beet. It was still a wild plant, something like a parsnip, when the discovery was made in 1747 that it contained a fair amount of edible sugar. Root crops (turnips, swedes, and mangolds) had recently been introduced into the rotation and were already creating a revolution in European farming. With the newly invented drill, they could be planted in rows where they could be cultivated; thus on land that would otherwise lie fallow the farmer could put in a crop and still keep down the weeds. In the second place, Robert Bakewell's discovery that he could use roots as winter feed in his sheep-breeding experiments provided an economic justification for the roots, and more importantly, by solving the problem of carrying animals through the winter it was making possible the great development in livestock farming which is one of the triumphs of eighteenth-century agriculture. The sugar beet offered a third advantage, in that it could become a cash crop. Yet it was fifty years before the first sugar-beet factory was opened, and it was not until Napoleon was cut off from the West Indies by blockade that Europe developed a real sugar-beet industry.

Even so, the sugar beet could never have reached its present production of some 40 per cent of the world's sugar unless human beings had made it quite a different plant from its wild ancestor. Nature's original plant was an annual, producing seed in its first year. Since this habit gave it too little time to develop its root, botanists converted it into a biennial, so that now it can grow and store sugar throughout an entire season and on into the autumn, without diverting its energies to seed production until the second year. Furthermore, it has been trained, by careful breeding, to store up a great deal more sugar than it was accustomed to do. Once the sugar beet was established as a sturdy, high-yielding crop of great industrial importance, geneticists have gone ahead to develop finer and finer varieties, giving the plant resistance to the major diseases and pests that attack it, increasing its sugar content still further, and in general making it more and more useful.

This is roughly the story of all new crops: man discovers in some plant, either wild or already cultivated for some minor purpose, a valuable property; farmers begin to plant it on a fairly large scale; then, as public acceptance builds up, agricultural scientists hybridize better and better strains, valuable by-products are discovered, and in the end a highly developed plant takes its place among the standard crops. In the past this whole process has sometimes taken centuries, as men waited for the knowledge or the incentive necessary to take the next step. Contemporary skill being what it is, the new crops now being introduced will in all likelihood be established much sooner.

Within one year, for example, an ugly, scratchy thistle called safflower sky-rocketed from obscurity into a million-dollar crop in California, yet work with it has barely begun. Like many "new" crops, safflower has been known and cultivated for a very long time. In India, the Middle East, and Africa, where it is native, it was grown primarily for its flowers, out of which men made a reddish dye. Europeans knew of it, but since the product was definitely inferior they contemptuously called the plant "bastard saffron" and made no effort to transplant and cultivate it. They knew that the seeds were relished by chickens and cattle, and they even knew that these seeds contained a fairly high percentage of vegetable oil, but it was not until the late 1940's that American chemists discovered properties in safflower oil so remarkable as to make its cultivation as a cash crop worth while.

When safflower oil is used in paint mixes, it is definitely superior to either soya bean or linseed oil. This alone would account for the premium price it commands and would make it interesting to farmers. But since safflower will grow in California, where soya-beans will not, the West Coast paint and varnish industry provides an immediate and eager market, because manufacturers can save the cost of a long freight haul from soya-bean fields in the Middle West. It is this fact that accounted for some 25,000 acres being planted in California in 1949-50, the first year of its introduction.

Of course this will not be the end of the safflower story. The staff of the Chemurgy Project of the University of Nebraska, where most of the basic work on safflower has been done, as well as a number of other investigators, are now at work producing varieties that are resistant to disease, breeding away the thorns that make safflower troublesome to handle, and increasing the oil content from an original 20 per cent up to nearly 45 per cent. At the same time, industrial scientists are searching for other uses of the new crop. They have already found that after the oil is expressed the seed cake that remains makes a good, high-protein livestock feed. More important, they are experimenting with the oil to determine its edible quality for human beings, and it appears that sooner or later safflower oil may find a place on the kitchen shelf.

Safflower has become a new crop because, although the plant itself was known for many centuries, only recently have scientists discovered the value that makes it worth large-scale cultivation. But the most exciting of the recent new crops is one whose actual value has been known for at least three thousand years; the difficulty was that no one knew how to convert that value to human use economically. The ancient Egyptians knew that in a tall, stringy weed called ramie, nature had created a textile fibre with almost miraculous superiority over any other fibre in the world. By tedious hard labour they were able to extract a small quantity of this fibre from the plant and weave it into cloth, and occasionally a bit is found in one of their tombs. The Chinese, in whose fields ramie has long been an agricultural pest, have also made of it a textile called "grass linen," but again they have done it by slow and laborious hand processes.

By the early eighteenth century, Europeans were well aware of ramie, and had begun to discover enough of its remarkable qualities to make them wish for machines that could handle it. They knew that the plant produces individual fibres as much as twelve inches long for example, whereas the fibres of our best cotton are a bare inch and a quarter. These long fibres can be woven into every kind of textile, from the thinnest gossamer to tough ropes as thick as a man's fist. And when they are woven into cloth, that cloth is virtually indestructible. I know a man who has been wearing six suits of underwear made from ramie for forty years! After innumerable washings they are still as strong and fresh looking as when they were bought.

Washing, indeed, seems to strengthen ramie. Even when it is soaked in sea water, instead of getting weaker, as most fibres do, it gets stronger. It washes more easily than other fibres, and yet it will hold dyes as well as any of them and better than most. It is not affected by mildew; it yields no lint; and it has a variety of other properties possessed by no other fibre, natural or synthetic.

For the past 150 years, textile experts have been racking their brains for a way to make ramie fibre available in large quantities. There are over a thousand patents in the U.S. Patent Office for machines that their inventors hoped would do the job. The sad fact is that none of them worked.

The difficulty is in the plant itself. It is a simple plant—just a straight stalk that grows up six or eight feet high, with a few large coarse leaves near the top. Inside the stalk is a woody core, and on the outside a skin, or bark. In between the core and the skin are the fibres, in long strips that run from the bottom of the plant to the top. The first step in getting the fibre is what is called "decortication," that is, the removal of skin and core without damaging the fibres. But this is exceedingly difficult, because the fibres are stuck together, and stuck to the skin and core, with a thick, resinous gum. The problem was to make machines that could decorticate the ramie and remove the gum.

Such machines were essential, of course, before any large-scale industry could be developed, because doing the work by hand is as slow and expensive as picking cotton fibres off the seed, the way it was done before Whitney invented the cotton gin. Besides that, when the work was done by hand, or by one of the primitive, imperfect machines, there was never any telling what quality of fibre would be produced. One batch might be fairly clean and straight, but in the next the fibres would be broken or snarled. Another would have gum left in it, and this would make it brittle and more or less useless.

Scientists all over the world struggled with the problem. For many years the British government had a standing offer of £5,000 for efficient decorticating and degumming machinery, but nobody was able to collect the prize. In Germany, at the beginning of this century, some machines were invented which did a fairly efficient job, and the Germans obtained concessions from the Russian Czar to grow the plant in what are now the Central Asian Republics of the Soviet Union. They were never able to produce a fibre of uniform high quality, but they did manage to sell in Berlin a small amount of clothing, including my friend's underwear, before the First World War put an end to their business.

There the matter rested until the late 1940's, when quite suddenly several machines and processes were developed, all of which produce unbroken, glistening white fibres. Already two American companies, using very different methods, are producing ramie in quantity, and other companies are forming to develop additional newly patented machines for the same purpose. Elsewhere, scientists are feverishly at work on processes they hope will be superior. All the machines so far invented employ different mechanical principles, they operate with different degrees of efficiency, and there is of course much argument about their relative merits. But the important fact, from the point of view of world economy, is that we are at last able to use on a large scale this most remarkable natural fibre.

So far, virtually all the ramie produced is being used for industrial products and not for clothing. The plant is barely becoming established in American fields, yet the fibres are already being made into everything from fire hose to fishing nets, and from heavy cordage to gas mantles and gauze bandages. And in every one of these products, there is some quality in ramie that makes it superior to other fibres. The reason doctors want it for gauze dressings is that it yields no lint. Canning factories have found that fruit-juice filters made from ramie will last many times as long as cotton ones. During the Second World War, the Army wanted ramie for tents and other equipment to be used in the wet tropics, because of its resistance to mildew; and the fact that soaking in salt water actually strengthens ramie made the Navy scramble for quantities to use as packing around propeller shafts.

There is at present very little ramie available for clothing or for the hundred-odd other textiles the ordinary citizen uses all the time. Our manufacturers may of course refuse to make us underwear or shirts or sheets or table linen which we can use for a lifetime, and with our craving for "fashion" we may imagine we do not want them. But as poverty-stricken millions learn of the possibility of such materials, the pressure for them may become irresistible. Already clothing manufacturers are buying small amounts of the fibres, chopping them down to the size of other textile fibres, and producing part-ramie goods, because they have discovered that this amazing fibre will not only mix with the others but that it always seems to impart its own peculiar qualities to the final product. Mixed with rayon it produces a cloth that can be washed, and wool with a small amount of ramie in it will not shrink. Since ramie absorbs more moisture than either wool or cotton, and yet throws off the moisture again much more rapidly, it can be used to make summer clothing which will never get clammy.

But what does all this have to do with the food problem? Scientists have not yet discovered any food values in ramie, except that the leaves make an excellent cattle fodder. By-products will doubtless turn up, as larger quantities are processed, but it seems unlikely that ramie will ever supply any noticeable amount of human food. Nevertheless, its introduction as a large-scale cash crop has an immediate and very significant bearing on the problem of supplying three or four thousand million people with the necessities of life. People must be clothed as well as fed, and the durability of ramie textiles would mean that more people could be clothed cheaply. But they could also be clothed from the yield of a far smaller acreage than we are giving to fibre production at present, and all the acres thus released could be planted to food crops.

To the southern cotton farmer this possibility may seem terrifying. Actually it would be a very great blessing. In the Gulf states, ramie grows well with little cultivation, and it yields three harvests a year. It will grow on marginal land, and on poor soil so depleted by one-crop farming that it will no longer produce cotton. With an assured market for such a crop, farmers could convert much of their best land to the production of food, and still enjoy a better income than they are receiving at present.

New crops have a way of revolutionizing the economies into which they are introduced, and the result is usually a rise in standards of living and a more economic use of cultivated land. Of course it may be a long time before men find another crop so rich in possibilities as ramie, but that the process of introduction will continue seems inevitable and some of the still-uncultivated plants will certainly increase man's ability to produce food. The botanical resources of this earth, though they are far richer than most of us would think, have been by no means completely explored. Of the more than 200,000 known species of plants, human beings are still cultivating fewer than 400 species for food. Notice that these figures refer to species, and not to varieties, whose almost infinite diversity we shall have occasion to consider at a later point in this chapter. Some species are known to have, like ramie, valuable properties which man is not yet skilful enough to utilize; others are like the safflower a few years ago, in that their real value has not yet been discovered. And there are many many more about which all one can say at present is that we do not know what riches nature may have hidden in them. As men gradually acquire more knowledge of the resources of this planet, we may expect newly introduced crops to continue, as they have done in the past, to enrich our economy.

In the meantime, the yields from crops already cultivated can unquestionably be increased. Such a simple thing as improved methods of fertilization could produce a great deal more food. Since 1898, when Sir William Crookes read his now-famous paper on the fixation of nitrogen, the use of inorganic fertilizers has become standard procedure in many parts of the world. Indeed, so many tons of chemicals have been heaped upon the fields that a strong countermovement has set in, with its advocates claiming that organic fertilizers are far better, both for the crops and for the land they grow on. The argument will doubtless continue indefinitely, to the benefit of everybody. For what is established beyond question is that plants, like animals and human beings, thrive best when they have plenty of food, and that when farmers increase the diet of their crop plants they are rewarded with higher yields.

Sound principles of fertilization are already so well known and so widely practised that it may seem falsely optimistic to suppose that they can contribute much more to the needed increase of food supplies in the future. Yet there are two facts to be noted. In the first place, the theory and practice of fertilization has quite recently been extended by certain discoveries which may be of considerable importance. For example, from the newest field of physical research, nuclear fission, has come an instrument that promises to increase the effectiveness of fertilizers very noticeably.

There was considerable excitement in the late 1940's when a Japanese scientist named Furuno reported that crops planted in the blasted soil of Nagasaki were producing unusually large yields. People in general, and particularly Americans, grasped eagerly at the hope that out of the incredible death and destruction we had wrought with our bomb, life might be reborn. Unfortunately for our peace of mind, the claims of Furuno have been largely disproved, and atom bombs remain to haunt our conscience as hideous means of devastation and nothing more.

But when the Furuno story was being widely circulated, scientists of the Canadian Radium and Uranium Corporation reported that for some years they had been quietly at work at a farm near Nyack, N.Y., testing the possible usefulness in agriculture of certain radioactive by-products from the atomic piles. They had found that some of these radioactive materials, added in minute quantities to ordinary fertilizers, could increase crop yields significantly. It is important to note that these materials do not take the place of the fertilizers. They simply act as "boosters," increasing the effectiveness of the plant food in some way which is not yet thoroughly understood. But the results have been increases in some instances of more than 50 per cent in the food weight of the harvest.

Another discovery that seems to have considerable practical value is one made in the course of some purely theoretical investigations by Professor W. H. Pearsall of the University of London, who has made many contributions to our knowledge of soils. Professor Pearsall, in the course of some studies of muck soils in the Cumberland marshes, noticed that there were measurable differences in what he calls the "oxidation-reduction potential" of boggy soil: oxidation of chemicals takes place at the soil-water surface, but reduction occurs lower down. When Japanese experts in rice culture heard about this, they knew that they had a key to the solution of a long-standing and troublesome problem.

They had long known that their rice yields would be much greater if they could apply nitrogenous fertilizers effectively, but they had tried various ones without much success. Sulphate of ammonia, applied at the time of transplanting or before, was sometimes effective, but more often it simply seemed to disappear without increasing the plant growth at all. Pearsall's discovery explained why this happened. When they had put the sulphate of ammonia on the surface of the mud, it had been quickly oxidized to nitrate, but as this nitrate washed down below the surface it was reduced to gaseous nitrogen, which the young plant roots could not utilize. The solution, then, was to push the sulphate of ammonia down through the oxidation zone into the region of reduction; there it would oxidize much more slowly, and the little roots would have time to absorb the nitrate as it was formed. Later on, during the period of rapid growth, ammonium and sodium nitrates could be safely applied as top dressings right on the surface, for at that stage the plants are able to absorb them quickly, before they reach the reduction zone and become useless.

To rice growers, who supply the staple food for half the world's population, Professor Pearsall's purely academic inquiries have thus given, for the first time, a scientific basis for the fertilization of their crop, and they are having fruitful results in other directions as well. Not only sulphate of ammonia, but cyanamide and other fertilizers are being studied in terms of the new knowledge of these oxidation and reduction zones, and agriculturists are learning that they are important in other soils and for other crops. The importance of proper placement of fertilizers has been demonstrated also, for example, in the onion fields of Michigan, where yields have risen 55 per cent as a result of our learning where to put the nutrients so that plants can make a better use of them.

Some indication of just how much remains to be done with fertilizers, even in countries like the United States, and how much the doing of it could increase production is suggested by the series of reports issued late in 1951 by the National Soil and Fertilizer Research Committee. This committee, composed of experts from the Department of Agriculture and from the Agricultural Experiment Stations of the various states, made a detailed study of yields in relation to soils and farming practices in the various sections of the country, and their general conclusion is that heavier use of fertilizers could produce some astonishing increases in yields. Western farmers, for example, are getting less than half of the potential yields on their present plantings of wheat, hay, and corn. If they would use more phosphoric oxide and nitrogen, they could produce, over and above their present output, nearly six million tons of hay, some forty-eight million bushels of wheat, and about ten million bushels of corn, without increasing their cultivated acreage at all. In the South as a whole, per acre yields of corn could be *tripled* if, in addition to more fertilizers, all farmers used adapted hybrids, spaced their rows more closely, and adopted other good farming methods in use elsewhere.

Such is the situation in the United States, where principles of both organic and inorganic fertilization are well established, and where chemical plants and factories for the conversion of organic waste materials are well able to supply the needs of agriculture. Elsewhere the picture is quite different. What is needed in less fortunate countries is widespread education in fundamentals, along the lines of the work done in some others by officially sponsored advisory services. Many of the technical advisers who are being sent into all parts of the world under the Point Four programme, and by the various agencies of the United Nations, seem to be making an excellent start in this direction. But the need is still far greater than the supply.

Larger yields, both from the present cultivated acreage and from the new lands to be developed, are an absolute necessity. There is a third branch of agricultural science which will help to produce them, and it is perhaps the most promising of all. It is the work of the geneticists and plant and animal breeders, those indefatigable meddlers with nature who are constantly changing the size and the shape and the quality of all her products.

The work of these men and women is symbolic of the most distinctive characteristic of our species: our unique ability to dominate our environment and bend it to the service of our creative will. The fact that we can change nature to suit our own purposes is what really distinguishes us from all other forms of life; more than any other trait or faculty, it is what we mean by calling ourselves *human* beings. Ever since his first appearance on this planet, man has consistently refused to accept the restrictions nature has tried to put around him, and he has constantly devised new and more clever weapons to implement that refusal. Nowhere have his triumphs in this direction been more brilliant than in his handling of the livestock and the food plants upon which his existence depends.

The breeder works with the genes, those minute particles in the germinal cells that determine the characteristics of individual living organisms. He has only a limited number of genes to work with, but the possible combinations are virtually limitless, just as endless symphonies can be constructed from the relatively few notes in a scale. What the geneticist does, essentially, is to provide opportunities for different genes to get together into combinations that would never occur in the ordinary course of natural events.

If he finds, for example, as desert scientists have found, that the native cattle in North Africa are a thriftless breed that eat more food than they produce, he does not fold his hands and complain that livestock farming in the desert is an impossibility. When this situation arose not long ago, Mr. Jean Etienne LeRiche, a South African livestock officer for the British administration in Tripolitania, simply looked around for a good meat-and-milk-producing draught animal that could be crossed with the native stock. All these requirements are not often found in one breed, but they do exist in the humped-back zebu oxen. Mr. LeRiche accordingly went to the Sudan and brought back some zebus by aeroplane. When these odd-looking beasts were crossed with the North African cattle at the Sidi Mesri station, the offspring were greatly superior to either of the parent strains. They were as hardy in the rough desert conditions as the native stock, but they produced much more meat and milk and were considerably more serviceable as draught animals. Since this new breed of cattle eat no more than the scrubbiest native, their introduction has virtually doubled returns from the available pasture.

In other parts of the Middle East, local conditions and requirements are being met by the breeding of other types. In northern Egypt, for example, the demand is for a small cow with high milk production. The native Damietta, the nomad's cow, meets the first of these requirements, and hence is able to get enough to eat from the scanty pasturage, but it gives in return a very small quantity of milk. This is the sort of problem that has been tackled at Burg-el-Arab, after Dr. Milad Bey's beautiful guest-house had fulfilled its purpose and the staff had settled down to their proper concerns. The Damietta has been crossed with imported Jerseys, and now there is at Burg-el-Arab a new breed of miniature cow which, although it eats daintily, gives a high yield.

The inhabitants of Iraq, on the other hand, prefer goat's milk to that of cows, and since other forms of power are available, they do not have the Tripolitanians' need for draught animals. They are, however, meat eaters. The emphasis in all the breeding programmes now under way in Iraq, therefore, is on beef, and the desert stock is being bred up by crossing with good imported meat-producing strains.

Much of the possible rejuvenation of the classic desert country depends on the continuance of this work in building up the herds, and on similar breeding programmes that have been started with sheep and poultry. And just as the development of water resources could be speeded up through some international agency that would co-ordinate the work of scientists in widely separated parts of the desert lands, so the great need in the whole livestock-development programme is for more interchange of information and techniques and facilities.

Genetics is really a field in which the international nature of scientific activity and the interdependence of one area on another are strikingly evident. If one wants demonstrations of the fact that humanity already inhabits one world, in which international boundaries and national restrictions are anachronisms, he has only to watch the breeders at their work. Very recently we in the United States have acquired a new kind of sugar cane that makes the labour of American cane workers much less arduous than it used to be, but it involved the close co-operation of many scientists and technicians in four countries.

The story began in the late 1930's, when some plant explorers hunting around in Burma found a wild sugar cane with an unusual and highly desirable characteristic. This wild Burmese cane has the habit of shedding its lower leaves, something that none of our domesticated varieties can do. The leaves on our cultivated canes remain on the stalk, where they dry up, clasping the sugarbearing stalk more tightly than corn husks cling to the corn. When the crop is harvested, those tough, dry sheaths have to be stripped off, and that makes a very rough job for the men and machines in the cane fields.

It was fairly easy to transplant the Burmese cane to Puerto Rican plantations and domesticate it, but this alone was no great advantage. Nature seldom creates anything exactly the way man would like it, and in the wild cane she had neglected to store any sizeable amount of sugar. But Dr. E. W. Brandes of the Department of Agriculture realized that if he could cross this cane with some of the cultivated varieties, he might be able to produce a self-cleaning cane with a high sugar content. Some of the Burmese cane was accordingly transplanted a second time, to Florida, where it was hoped a cross could be made.

At that point nature baulked. The wild cane did bloom, and although the flowers were scanty there was still a sufficient amount of pollen. The trouble was that the twice-transplanted cane produced its flowers weeks ahead of any variety in this country; the pollen was available, but we had not a single plant that could receive it.

Then Dr. Brandes and his fellow workers began a search for some useful variety of cane that bloomed at the same time as the Burmese variety. They combed through the records of blooming dates compiled at all the plantations and experimental stations in the whole cane-growing area of the Caribbean and Central and South America. Eventually, records of three strains were found, all of them from an agricultural station in Colombia. Since plants cannot be married by proxy, Dr. Brandes had to work out a rather ingenious trick. He waited until the wild cane was well established in Puerto Rico, and when it came in bloom there again, one of the American team, Dr. George Sartoris, was dispatched to the island by plane. In the Puerto Rican fields, Dr. Sartoris carefully collected some of the Burmese pollen in little bottles, which he packed into specially designed refrigerated containers. Another plane took him to South America, and at the Colombian station he made the cross-fertilization.

Six weeks later, seeds from the new hybrid arrived in Florida. Plants were grown from these seeds, and to everybody's relief it was found that the wild cane from Burma had transmitted its cleanly habits to its half-breed descendants. It appears that the rough job of stripping the leaves from American canes will be done away with, and our cane fields will be pleasanter places to work.

The objective of all this effort with the sugar cane was simply human convenience, and it is remarkable how much trouble scientists will go to in order to make human life and labour less bothersome. They have bred out of Sonora wheat the irritating fuzz that used to give California farmers a nasty ailment called Sonora itch; breeding out of tiny hairs on the leaves and hulls of rice made a similar improvement in the working conditions of rice handlers. Right now, the geneticists are engaged in changing the shape of the sugar beet, from the long, parsniplike root which machines cannot harvest to a nearly globular variety that sits loosely in the soil and topples out of the ground at a slight pull on its foliage.

The most important work of the plant breeders, however, is directed toward producing varieties that will give the farmer a greater yield in return for no more labour on his part. In the past quarter century, the results of hybridization for this purpose have been astonishing. Everyone knows that American farmers have been gathering annually larger harvests of hybrid corn, until now it ranks as our greatest single crop, but it is not so well known that these constantly increasing yields have come from fewer and fewer acres every year. Maine potato growers are digging 75 per cent more potatoes per acre than they did twenty years ago, and the yields of Dakota wheat are up by 20 per cent. Since the First World War, Dutch geneticists have doubled the sugar content of Javanese canes. And in one of the most exciting contemporary feats in plant genetics, Soviet scientists have produced a variety of wheat that bears five or more heads on a single stalk, in contrast to the one head per stalk that is characteristic of all other wheat. This achievement, incidentally, is not simply a piece of Soviet propaganda; it is confirmed by our own Department of Agriculture. If a plant of such bountiful productivity could be established in all the major wheatlands of the world, it would become fatuous to talk about the possibility of bread famine.

There is no earthly reason to suppose that such triumphs will mark the end of human efforts to create higher yielding varieties of all the basic crop plants. On the contrary, we may be very sure that sooner or later geneticists will develop many hybrids quite as remarkable as branched wheat. Apart from the fact that in any field where so much has been accomplished it is reasonable to suppose that more will be attempted, there are two reasons for such confidence. One is the wealth of acquired knowledge, and the other is the still-considerable amount of human ignorance. Both will operate to increase yields.

The scientists are better equipped than they have ever been to undertake productive study in genetics. This is true not merely because of the mass of information that has accumulated, but because of the incalculable potentialities of the newer instruments. For example, a vast field has been opened up by recent experiments with X-rays. When nature creates a new variety of any species, having characteristics markedly different from those of its progenitors, she does it accidentally; something goes wrong with the genes, and the resulting oddity is called a "sport." When this sport transmits its own characteristics to its offspring, a new variety has come into existence. Recently, scientists have discovered that they can purposely produce sports: by exposing seeds to X-rays, the genes can be shaken up in all sorts of ways, so that the plants which finally grow from them may be sports of various kinds. Some are deformed and monstrous, but in others the juggling of genes may produce mutations of the most extraordinary usefulness to man. When after X-ray treatment a plant emerges that gives a much larger yield of some useful material than is customary, the scientists attempt to "fix" this characteristic by careful selection and breeding. The successful outcome of such experiments adds a new and valuable variety to the list of man's cultivated crops.

Not a great deal has been done so far to create new combinations of genes by exposing seeds or bulbs to X-rays, but what has been accomplished has shown that the possibilities are very great. An even newer technique is the use of isotopes from the atomic piles to aid geneticists in the basic research they must constantly be doing. With these "tagged atoms" to guide them, scientists in every department are able to trace all sorts of processes which were formerly completely mysterious. They are inspired not by mere curiosity, for they have long since learned that if once they can find out how nature performs some transformation of matter, they are well on the way to being able to perform it themselves.

Of even greater promise than this increasing knowledge and skill is the growing realization that human ignorance of the world we live in is still vast. If it is true that the profoundest fool is the man who imagines he knows all he needs to know, then certainly one of the great contributions of modern science is its pointing out some of the enormous areas of possible knowledge which have not yet been explored. Recently it has begun to give some inkling of the number of plants in the world which have not yet been investigated.

The fact is that although nearly four hundred species of food-producing plants are known, nature has created an enormous number of varieties of most species, and many of these varieties have characteristics that could be of very great service. One would think that in the United States, where hybrid corn was developed, our agriculturists would have a nearly complete knowledge of the many types of corn that are found in nature. Yet, Dr. I. E. Melhus, the chief botanist at Iowa State College, reminded us in 1946 that only 15 per cent of the world's corn varieties had so far been studied. Some indication of the riches that may be discovered when they are can be gathered from the reports of a scouting party sent out by that same college. In one small country, Guatemala, the expedition observed all sorts of native corns that had never been known to the scientific world. They found varieties that were highly resistant to drought and disease and insect pests; they found corn with ears 2 feet long, varieties with stalks as tough as bamboo which could be used for building, and still other varieties as much as 28 feet tall.

Nature has created varieties of most of the common crop plants in far richer diversity than was once supposed. The many types of potatoes now cultivated in North America and Europe have all been developed by man from two or three varieties that were discovered three and a half centuries ago. Yet Russian botanists, attempting a world survey of plants in the period between the first two World Wars under the leadership of the late N. I. Vavilov, found literally hundreds of native types of potatoes in South America, of all conceivable shapes and sizes. Some had tubers with coal-black flesh; others were purple, or pink, or cream-coloured.

Each was different in flavour and consistency from the others, but all were edible, and were in fact cultivated by the native people for food. Some were immune to potato blight; some could resist the Colorado beetle; still others were growing at elevations ranging up to 14,000 feet, undamaged by the nightly frosts.

This same expedition, looking in many countries where the flora had not been systematically studied, found entirely new varieties even of such well-known plants as wheat. They discovered barley with smooth awns, and other varieties that were resistant to the ravages of the fruit fly. Among the more exotic plants they catalogued were such things as an edible honeysuckle, and even a mountain ash that furnishes good food for human beings.

Similar expeditions, studying the botanical resources of one corner of the world or another, have come back with the same kind of information. The conclusion that can be drawn from the evidence already in is twofold. In the first place, there exist varieties of hundreds of common food plants with valuable characteristics possessed by none of our cultivated types; by crossbreeding with them, yields could be increased and quality improved. Beyond this, the astonishing discoveries made through rather sporadic investigation give good reason for believing that a systematic search on a world-wide scale would provide even richer materials.

Fortunately something is being done about it. The Food and Agriculture Organization is at present working on what it calls a "World Catalogue of Genetic Stocks," for the express purpose of bringing together all the information we now have about our botanical resources, increasing that information as fast as possible, and making it available to geneticists and plant breeders who can use it. Scientists in each nation are given the responsibility for maintaining the varieties, species, and breeding stocks of plants that grow in their own territories, and forwarding to the central clearinghouse in Washington complete information about them. All this information is tabulated and arranged, and it is then made available to other scientists anywhere in the world. Thus a man who wants to help the farmers of his country combat the potato blight, for example, by producing a variety that is resistant to the disease and yet has all the desirable qualities of the types his countrymen grow, can find through the FAO catalogue exactly what resistant varieties may exist, where they are, and how to obtain specimens he can work with.

The catalogue was begun with wheat and rice, since these are the cereals upon which the majority of human beings depend for their basic food. The next group of plants to be included are the forage crops, and here the emphasis is particularly on crops that can be grown in tropical and sub-tropical regions, because those areas are going to become increasingly important as producers of livestock. Here one of the big problems is to find plants that will do for farming in those areas what root crops did for Europe, that is, supply food for cattle during certain critical periods of the year when the customary feed is always in short supply.

This is the kind of work in which scientists of the whole world can participate. Those who live where agricultural science is already highly developed can draw far more heavily on the resources of countries where the flora have been, until recently, virtually unexplored. At the same time, the results of the best hybridization work in the most highly advanced countries can more easily be sent to aid farmers in countries that cannot yet do the technical work themselves.

It becomes more imperative daily not only that our collective knowledge in general be more widely shared but, specifically, that the best varieties of all the standard food plants be made available everywhere. The fact that cane fields in Java now produce approximately six tons of sugar per acre is vastly encouraging, but the sobering contrasting fact is that the world average yield is less than a ton and a half. Wheat harvests in Great Britain have risen from 800 or 1,000 pounds per acre to an average of 2,000 pounds, yet the world average is still no higher than 700 pounds. Even in such excellently farmed countries as England, the high average yield can be raised, for the best British wheat farmers are getting 3,000 and 4,000 pounds from every acre they plant, and there are many other farms that could be built up to similar productivity. In milk yields there is a similar situation: the average in England and Wales is around 550 gallons from each cow, but registered herds average 700, and in fine, highly bred herds the average cow gives 1,000 to 1,200 gallons.

Clearly, the most vital task that confronts us in the immediate future is that of bringing up the yields of the whole world to the levels already achieved by the best farmers in the most advanced countries. This of course involves a great deal more than the wide distribution of the best varieties of food plants, but such distribution nevertheless remains essential. Just as we are now beginning to send our hybrid corn to India, to Europe, and to other lands, so it is to be hoped that when the new branched wheat is as thoroughly established, the Soviet Union may begin to export it. Countries that are already producing embarrassing surpluses which they cannot dispose of profitably would in all likelihood refuse it, but there are other countries where it is badly needed and would doubtless be welcomed. Certainly it would seem that there is a moral obligation on all humanity to help the world's farmers, wherever they may live, to obtain seeds that will yield the maximum of food. And although some good starts have been made in the right direction, this is an undertaking that calls for considerably more international co-operation than is practised at present.

At least we can begin with the knowledge that there is no valid scientific or technical reason for the present low average yields from the world's cultivated land. Scientists know that our harvests can be increased, and they know precisely how to do it. Man is no longer a helpless creature who must take only what nature in her carelessness and indifference throws his way. He can control the sources of his livelihood; he can change nature to suit his own purposes; he can create abundance if he will.

CONCLUSION

XII. THE OPENING DOOR

FROM THIS necessarily limited survey of man's productive capacities, it would seem that there is no occasion for abandoning ourselves to pessimism and self-defeat. This planet is not limitless, but it is sufficient for the support of all who are likely to live on it. What is perhaps more to the point, human beings have reached a stage of technological development where they can produce from the available resources not merely subsistence, but abundance.

Some say that mankind has come again, at this mid-point in the twentieth century, to one of those decisive moments in history that mark either the end of a great period or the beginning of one yet more significant. Such times are not easy; but for bold spirits they are exciting and challenging.

Among the numerous deities to whom the prudent citizens of Rome gave recognition and occasional honour, there was one called Janus the porter. He was the gatekeeper for the high gods, the opener of doors, the guardian and patron of all entrances and beginnings. A people less astute than the Romans might have represented such a deity as an adventurous youth, his eager face flushed with hope and his eyes filled with the certainty of the richer, happier world that must lie beyond the opening door. But Janus is never represented in this way. In all his statues, he is shown as a bearded man, mature, and indeed a little tired, and his bewilderment before the door of the future is expressed in a hideous deformity: two deeply human faces, staring in perplexity in opposite directions. His single brain, struggling to resolve the contradictory evidence of his two sets of eyes, is stunned in an agony of indecision.

Whoever first invented Janus had a profound understanding of the human dilemma. It is our ability to think and to reason, "to look before and after," to choose between alternatives, that brings us up short again and again before a door that can swing in either direction. If we were merely animals, we should plunge ahead blindly like the Gadarene swine, driven by forces we could in no way control or even understand. But since we are not swine, every doorway is a challenge to decide our own course.

What seems to be mainly required of us in our present situation is that we make the fullest possible use of the resources, the knowledge, and the skill which we undoubtedly have. Past generations have found that a new technology, although it created population problems, was adequate to solve them if it was energetically applied. At the same time, they have made the sometimes bitter discovery that the new difficulties could be solved in no other way. The greatly increased needs of stone-age farming communities could not be met by using the tools and tricks of savage, foodgathering societies. Weapons, charms, forms of social organization, and modes of behaviour which had been perfectly adequate to the hunter failed miserably to coax out of the earth food for a settled agricultural people. In order to survive, the farmer had to use, and to use with all his strength and cunning, the ideas and the inventions that had freed him from the bondage of the nomad in the first place.

No one need doubt that the productive instruments in human hands today can be just as effectively used. There is hardly a nation in the world which is not using at least a few already. And despite the limitations which nationalism still imposes, co-operation along international lines is constantly becoming more effective.

The industrialization of the backward economies of the world, which must be the primary factor in any programme for solving the food problem, can be achieved only by worldwide effort. Neither deserts, arctic regions, nor tropics lie wholly within the jurisdiction of any one government; whales are hunted by a dozen nationalities whose homes are far away from the Antarctic; and the vast frontier of the oceans begins at every coast line on the planet. The tropical area of South America is a geographic unit, but politically it is divided among twelve governments and it can be developed only by the concerted action of all of them. Locusts and tsetse flies do not recognize the boundary lines on the maps of Africa, and the virus of rinderpest knows no difference between an Ethiopian cow and a Chinese water buffalo. Even individual projects like the plans for controlling the Jordan and making it enrich the lives of all who live within the area of its potential usefulness cannot be carried out as they should be except by the agreement and co-operation of friendly governments. So long as Arab fights with Jew, so long as communist and non-communist persist in imagining that they cannot work together for the common good, the creation of a world in which hunger may not drive us into yet greater follies will be delayed.

Modern governments are not, however, incapable of combined efforts toward common goals. In the midst of world war, the Middle East Supply Centre did control the locusts and protect the food resources of eighty million people. More than a dozen different governments are actively pooling their money and skills in the Colombo Plan though the land that will be directly benefited by their labour lies thousands of miles away from the territories of four of them. The pan-American republics have long since found ways of co-ordinating their work on regional problems, and through the Point Four programme and other agencies some of the wealth and technology of the United States is being fairly exchanged with nations in both hemispheres. And never in history have so many governments been active members of such organizations as the various United Nations agencies. It is true that the Soviet Union and countries in the Soviet orbit are not at present contributing to these great international channels of energy, and that their absence is a serious limitation. Nevertheless, almost all the other nations are actively at work together, each sharing according to its abilities and its needs, and every day they are learning more effective ways of doing it.

There are obstacles, of course. In some projects the nations are learning that economic forms, if they are not compatible with needs and resources, can sometimes frustrate efforts toward increased production. Much good land is uncultivated for reasons that have nothing to do with the world's hunger but purely because the economy in which some farmers live does not permit their potential yield to be distributed and consumed. To solve such a problem the governments are groping toward some kind of world food bank; through FAO they have already examined one such plan, and the fact that it was rejected only indicates their concern to find a more acceptable one.

The problems are not limited to food. Billions of cubic feet of natural gas are wasted in the fields because no one has yet figured out a way to make its conservation worth while. The timber industry, nearly everywhere, is a standing example of uneconomic use of a natural resource. But as they look at such facts together, trying to bring them into a focus where they are clear and meaningful to all, the representatives of many nations with different economic backgrounds are beginning to see that a variety of approaches is possible.

Wherever economic forms limit production and waste products; wherever they prevent farmers from distributing all their labour can produce; wherever they divert human energies into destructive, instead of constructive, channels—in such situations new economic arrangements may be needed. We in the United States, who understand our own economy better than any other and are sometimes prone to imagine that it would work for all peoples as well as it has for us, may find it necessary to realize that in many parts of the world the chief stumbling block to the rational use of science is the system of private ownership and private profit. Certainly until we recognize that there are more vital rights than the rights of the absentee landlord, we cannot very effectively help to solve, for example, the problems of the Middle East.

One thing most men and their governments are already prepared to admit: in the giant work of conservation, reclamation, and development which men must undertake as a world community if they are not to perish, no one economic order has or can have any monopoly. The rejuvenation and settlement of the Ninety-Mile Desert in Australia is a purely capitalist venture, launched by a private insurance company for the purpose of making a profitable return to its investors, yet it is unquestionably performing a social service of the first importance and adding greatly to the wealth and the productive capacity of the world. The diversion and control of rivers in the Soviet Union is by contrast being done within the framework of a socialist economy by a communist government, but its contribution is just as undoubtedly great. The kans clearance work in India is a state enterprise, supported partly by Indian government funds and partly by a straight commercial loan on which the lenders will earn a profit. On the other hand, the splendid reclamation in the valley of the Guir in French Algeria is a project carried out by a colonial power, financed by assessments on the taxpayers in the imperial country; yet the rich land is being handed over in 1,000-acre tracts to be cultivated by collectives, which is thought to be a communist invention. Nor should we ever forget the vigorous individual: Alec Hay, Joe Ward, and George Thompson built their sea wall themselves out of their own pockets, and the estate of Lord Iveagh is a brilliant example of individualistic capitalism at its finest, on the scale of very big business.

One small country is today a veritable laboratory of economic experiment, where one can see all sorts of different arrangements working harmoniously together. Israel is tackling the problem of vastly increased food production more vigorously than any nation in the world. In doing it she is using successfully almost every economic form that is still practised in the modern world: here a factory or a waterworks or a farm privately owned and operated at a profit; in another place a completely socialist organization, in which the means of production are owned by a municipality or by the national government, and the product is distributed sometimes at a profit and sometimes at cost. Some land is owned by the state and leased or rented or sold under long-term loans at low interest, while some is farmed co-operatively and its products handled through other co-operatives. And there are even many collectives in which the ownership and the sharing of returns is worked out on a completely communistic basis.

There appears to be no reason why a similar variety of approaches may not lead to the successful completion of the programme which groups of nations must set for themselves if they are to avoid the calamities that hunger, spreading among four thousand million frantic human beings, would certainly bring upon them all.

Can the nations afford the plain money cost of such a programme? The simplest answer to this fundamental question is that they can less afford the incalculable cost of failing to attempt it. Such an answer is not much help, of course, unless the needed work can actually be financed. There is good reason to believe that it can be.

Frequently, in earlier chapters of this book, it has been evident that the amounts needed for a given project were actually small. Many of the much-needed developments would be entirely self-liquidating, so that if only the initial capital were available the job could be financed on a straight commercial loan, the loan repaid, the new project therefore acquired without any real cost at all, and the money put back into a general pool to be drawn on for further projects. This is the principle on which capital is furnished through such international lending agencies as the Export-Import Bank and the International Bank for Reconstruction and Development.

So far as the total effort is concerned, the need of the world has not as yet been put into any exact figures, and probably cannot be. The most reliable general estimate is one submitted by an international group of experts to the Secretary-General of the United Nations in 1951. It is an extraordinarily detailed study of the requirements for bringing *all* the underdeveloped countries—in Africa, the Middle East, Latin America, and all of Asia—up to a fairly high standard of industrialization in a period of from ten to twenty years. As such, it involves far more than the food problem. But for even this gigantic undertaking, the estimate of foreign capital needed in loans, grants, and investments was in the neighbourhood of 10,000 million dollars a year. This is admittedly a very large sum. The necessary production of food, which is the fundamental problem, would certainly cost less. But this is the kind of round figure which the nations that are able to make investments must be prepared to consider.

Is it beyond possibility? It is roughly 3 per cent of the total national incomes of western Europe, Australia, the United States, and Canada. It is about one-sixth the amount the United States alone is spending annually for rearmament, and a mere fraction of the total annual armaments bills of all the powers, if we include not only the non-communist governments but the communist ones as well.

Yet it is an approximation, at least, of the sums which, if wisely spent, could solve not only the food problem but a host of lesser ones. Within a reasonable time, investment of this size could transform all the backward economies that now enforce an inescapable misery upon more than half of the earth's people into industrialized societies, whose individual members could earn with their labour the comfort and dignity which is their human birthright. It could produce the kind of world in which men might find freedom from fear.

Few generations have had the task of providing for so many additional people. None has had the opportunity to lift the whole of humanity so far above its previous conditions, to a stage where the full resources of human creativeness could be released. It would be foolish to regret that men cannot go on precisely as they have gone in the past, when they can go in better ways to an infinitely better future. The knowledge, the technical skill, and the physical equipment now available are more than ample for the need. We who are now living have no grounds for irresponsible optimism, but we have every right to sober confidence. This attitude can indeed be the decisive factor that will give to all men their daily bread.

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